Policy instruments, research and development, innovations and technology diffusion in a north-south structure

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Policy Instruments, Research and Development, Innovations, and Technology Diffusion in a North-South Structure

Instruments Politiques, Recherche et Développement, Innovations et Diffusion de la Technologie dans une Structure Nord-Sud

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"Innovation distinguishes between a leader and a follower."

Steve Jobs (1955-2011)

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List of Acronyms

BRL	Brazilian Real
CAP	Common Agricultural Policy
CEPII	Centre for Prospective Studies and International News (*Centre d'Études Prospectives et d'Informations Internationales*)
DESTATIS	Federal Statistical Office of Germany (*Statistisches Bundesamt*)
DSB	Dispute Settlement Body
EPO	European Patent Office
EU	European Union
EUR	Euro
FE	Fixed Effects
FDI/*IDE*	Foreign Direct Investment (*Investissement Direct Étranger*)
GDP/*PIB*	Gross Domestic Product (*Produit Intérieur Brut*)
GLS	Generalized Least Squares
IAC	Industrially Advanced Country
IDC	Industrially Developing Country
IFPRI	International Food Policy Research Institute
INSEE	(French) National Institute of Statistics and Economic Studies (*Institut National de la Statistique et des Études Économiques*)
ISO	International Organization for Standardization
ITC	International Trade Centre
LAREFI	Centre for Analysis and Research in International Economics and Finance (*Laboratoire d'Analyse et de Recherche en Économie et Finance Internationales*)
MAcMap	Market Access Map
MERCOSUR	Common Market of the South (*Mercado Comun del Sur*)
MNF	Multinational Firm
OECD/*OCDE*	Organization for Economic Co-operation and Development (*Organisation de Coopération et de Développement Économiques*)
OLS	Ordinary Least Squares
R&D	Research and Development (*Recherche et Développement*)
RE	Random Effects
SPS	Sanitary and Phytosanitary
TBT	Technical Barriers to Trade
TFP	Total Factor Productivity
TRIP	Trade-Related Aspects of Intellectual Property Rights
TS	Technical Specification
UK	United Kingdom
UNCTAD	United Nations Conference on Trade And Development
US	United States
USD	United States Dollar
VER	Voluntary Export Restraint
VIF	Variance Inflation Factors
WDI	World Development Indicators
WIPO	World Intellectual Property Organization
WTO	World Trade Organization

POLICY INSTRUMENTS, RESEARCH AND DEVELOPMENT, INNOVATIONS, AND TECHNOLOGY DIFFUSION IN A NORTH-SOUTH STRUCTURE

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JEL Classifications: F12, F13, O30, O33

-SUMMARY IN FRENCH-

RÉSUMÉ EN FRANÇAIS

Instruments Politiques, Recherche et Développement, Innovations, et Diffusion de la Technologie dans une Structure Nord-Sud

CHAPITRE 0 – Introduction Générale

La question des innovations technologiques est prépondérante en économie. Elle rejoint l'accès à des biens et services nouveaux, parfois de plus haute qualité, pour le consommateur. Elle est liée également à la question de la compétitivité des offreurs d'un pays qui se définit comme la capacité à vendre face à une concurrence internationale. Cette compétitivité contient d'ailleurs deux volets : la compétitivité-prix et la compétitivité hors-prix. La première correspond à la capacité de vendre un produit à caractéristiques équivalentes de ceux des concurrents mais à un prix plus faible. Ainsi, être plus compétitif passe par la réduction des coûts de production. Les innovations peuvent être source de compétitivité-prix si elles sont réductrices de coûts de production (*cost-reducing*). La seconde correspond à la capacité de vendre un produit à un prix identique de ceux des concurrents mais avec des caractéristiques différentes (notamment à qualité supérieure). Les innovations peuvent alors stimuler la compétitivité hors-prix si elles permettent de différentier le produit final verticalement par rapport à ceux des concurrents.

Un indicateur potentiel d'innovations technologiques correspond aux dépenses d'investissement en Recherche et Développement (R&D). Il s'agit d'un investissement dans la connaissance qui se définit comme *« les travaux de création entrepris de façon systématique en vue d'accroitre la somme des connaissances, y compris la connaissance de l'homme, de la culture et de la société, ainsi que l'utilisation de cette somme de connaissances pour de nouvelles applications »* et regroupe *« la recherche fondamentale »*, *« la recherche appliquée »* et *« le développement expérimental »* (Source : Définition de l'INSEE). Comme nous l'avons précisé avec la compétitivité précédemment, il y a deux types d'investissement en R&D. Le premier type correspond à la R&D de procédé (*process R&D*) qui est réductrice de coûts de production (*cost-reducing R&D*). Ce type d'investissement permet alors d'augmenter la compétitivité-prix. Le second correspond à la R&D de produit (*product R&D*) qui est innovatrice en termes de caractéristiques du produit vendu. Il engendre alors une hausse de la compétitivité hors-prix en contribuant à différentier le produit verticalement de ceux des concurrents.

En économie internationale, la littérature a d'abord étudié le concept d'investissement en R&D dans un cadre théorique. Le modèle de référence est celui de **Brander et Spencer (1983)**. Les auteurs utilisent un modèle d'équilibre partiel en duopole où les firmes investissent en R&D. Il s'agit en l'occurrence d'un investissement en R&D réducteur de coût de production. La structure est particulière : le jeu s'effectue sur l'investissement en R&D. Ainsi, à l'équilibre, les firmes choisissent un niveau optimal d'investissement en R&D maximisant leur profit. Elles choisissent ensuite le niveau optimal de production ; les auteurs faisant l'hypothèse d'une concurrence de type Cournot (sur les quantités produites). D'autres études s'intéressent au cas de la R&D de produit. Il est montré d'ailleurs que les firmes ont tendance à investir plutôt en R&D de produit au début du cycle de vie d'un produit puis en R&D de procédé à la fin (**Utterback et Abernaty, 1975** ; **Klepper, 1996**). Le modèle théorique de référence en présence de R&D de produit est celui de **Park (2001)**. Il considère un duopole avec une firme d'un pays riche produisant un bien de haute qualité (*high-tech firm*) et une firme d'un pays en développement produisant un bien de faible qualité (*low-tech firm*). Chaque firme vend son bien dans un pays tiers. La qualité dépend des dépenses en R&D réalisées. La différentiation verticale entre les deux produits provient bien de la différence en termes d'investissement en R&D.

L'investissement en R&D a une importance cruciale pour les économies industrialisées qui font face à une concurrence croissante de pays disposant d'avantages compétitifs liés à des coûts de production plus faibles, notamment un coût du travail bon marché. La question est de savoir comment ces économies développées peuvent stimuler les innovations technologiques domestiques, c'est-à-dire les dépenses en R&D. Il convient de s'intéresser à l'impact potentiel de la mise en place d'instruments politiques mis en place par les pouvoirs publics de ces pays afin d'identifier des leviers qui permettent d'encourager les innovations.

Si l'importance de la technologie au niveau de la compétitivité d'un pays et de ses indicateurs économiques et commerciaux est incontestable, celle de sa protection et de sa diffusion l'est tout autant. Dès qu'un innovateur découvre une nouvelle technologie ou crée un produit nouveau, il dispose d'un monopole temporel sur l'utilisation de cette nouvelle technologie ou sur la vente de ce produit nouveau. Nous parlons d'ailleurs d'une durée de monopole pour l'innovateur. Celle-ci correspond également à la rapidité de la diffusion technologique vers les concurrents. Elle dépend de la capacité des concurrents à innover en investissant en R&D également. Mais dans le cadre des pays en développement, les niveaux des dépenses en R&D sont assez faibles. Ils profitent plutôt d'effets de débordement, autrement appelés *spillovers*, provenant des innovations effectuées par les pays riches plutôt que de réaliser leurs propres innovations. La diffusion technologique est effectivement cruciale pour les économies du Sud. Précédemment, nous avons précisé l'importance des innovations technologiques pour les économies riches tant elles pouvaient stimuler leur compétitivité face à une concurrence de plus en plus importante du monde émergent. La question de la diffusion technologique met en avant une réelle problématique de développement économique, humain, social ou encore sociétal pour les pays à revenu modeste. La diffusion de la technologie est un processus qui peut être difficilement remis en cause à l'échelle mondiale, mis à part dans les pays les moins avancés, éventuellement, qui ont pour l'instant un retard structurel trop important. Sinon, le réel débat n'est pas de savoir si la diffusion de la technologie va avoir lieu entre pays du Nord et pays du Sud mais plutôt de savoir à quelle vitesse. La variable à analyser est donc la rapidité de la diffusion technologique.

La littérature économique s'est également intéressée à la question de la diffusion technologique en illustrant trois sources principales de diffusion : le commerce international, les IDE et les *spillovers* de R&D (**Keller, 2004**). Un apport important est celui de **Grossman et Helpman (1991)**. Ils démontrent, dans une structure théorique, l'importance du commerce des biens intermédiaires comme déterminant de la vitesse de la diffusion technologique. Au niveau de la mesure de la diffusion technologique, l'élasticité de la Productivité Totale des Facteurs (*Total Factor Productivity*) par rapport à différents facteurs de diffusion tels que le commerce ou les IDE est un instrument potentiel (**Keller, 2002**). Un autre instrument potentiel correspond aux collaborations de brevets entre pays (**Fleming et al., 2007** ; **Guan et Chen ; 2012**).

La question est de savoir de quelle manière les instruments politiques peuvent influencer la vitesse de diffusion technologique entre pays riches et pays en développement. En effet, une fois avoir identifié l'impact des instruments politiques mis en place par les gouvernements des pays riches sur l'investissement en R&D local, il faut également analyser l'impact sur la diffusion de la technologie vers les pays à revenu modeste. De la même manière, il peut être intéressant d'étudier l'impact d'instruments politiques mis en place également par les pays du Sud pour voir s'il peut y avoir un intérêt notamment en accélérant la diffusion de la technologie.

Le but de ce travail est de fournir des éléments de réponses aux questions suivantes :

- Les firmes issues de pays riches sont-elles incitées à innover lorsque leur gouvernement domestique met en place des instruments politiques ?
- Les résultats sont-ils robustes à un changement de type de R&D (de procédé ou de produit) ?
- Ces instruments politiques accélèrent-ils ou ralentissent-ils la diffusion de la technologie vers les pays émergents ?
- Quels sont les déterminants empiriques significatifs de cette diffusion de la technologie ?

CHAPITRE 1 – Instruments Politiques, Recherche et Développement Réductrice de Coûts, et Incertitude dans un Duopole Nord-Sud[1]

Les pays du Nord font face à une concurrence croissante des pays du Sud qui bénéficient de coûts de production plus faibles, via un coût du travail bon marché notamment. Les décideurs politiques des pays industrialisés cherchent à mettre en œuvre des moyens permettant d'inciter les producteurs locaux à innover, via un investissement en R&D, afin de limiter les coûts de production. Un certain nombre d'études théoriques ont montré que la mise en place d'instruments politiques pouvait stimuler la R&D domestique : une subvention de la R&D (**Spencer et Brander, 1983** ; **Leahy et Neary, 1997**), une subvention de la production (**Leahy et Neary, 1997**) ou encore un tarif sur importations (**Krugman, 1984** ; **Reitzes, 1991** ; **Bouët, 2001**). En contrepartie, des restrictions quantitatives sur le commerce peuvent être néfastes (**Reitzes, 1991** ; **Bouët, 2001**).

Ce premier chapitre fournit une analyse exclusivement théorique quant à l'impact d'une sélection d'instruments politiques, notamment de politique commerciale, sur l'investissement en R&D. Il convient alors de considérer un cas de figure simple d'un duopole Nord-Sud. Chaque firme vend une partie de sa production localement et exporte le reste vers le pays étranger. La firme du Sud bénéficie d'un coût marginal faible lié à un coût du travail bon marché. De ce fait, elle n'investit pas en R&D. Concernant la firme du Nord, nous reprenons l'hypothèse d'incertitude quant au résultat de la R&D illustrée par **Bouët (2001)**. L'investissement en R&D peut se traduire par une réussite. Dans ce cas, le coût marginal de la firme du Nord est faible, comme celui de la firme du Sud. Mais il peut également se traduire par un échec. Dans ce cas, le coût marginal est plus élevé que celui de la firme du Sud. L'investissement en R&D se traduit par une réussite sous une probabilité qui dépend positivement du niveau de cette R&D mais avec des rendements décroissants. Cette hypothèse de rendements décroissants est très importante car elle conditionne la majorité des résultats de ce chapitre. Elle est d'ailleurs tirée de la littérature économique (**Spencer et Brander, 1983** ; **Reitzes, 1991**). La firme du Nord va chercher à maximiser un niveau d'espérance de profit compte tenu du résultat incertain de la R&D. Pour cela, elle choisit le niveau de R&D optimal. L'investissement en R&D est coûteux et s'ajoute au coût total de production, pesant ainsi sur le profit espéré. À partir de l'hypothèse de rendements décroissants de la R&D, nous pouvons démontrer que l'investissement en R&D d'équilibre est une fonction croissante de ce que nous appelons le différentiel de profit de la firme du Nord et décroissante du coût unitaire de la R&D. Ce différentiel désigne la différence entre le profit de la firme du Nord en cas de réussite de la R&D et celui en cas d'échec de la R&D. Une fois que la

[1] Ce chapitre a été coécrit avec Antoine Bouët (LAREFI, Université de Bordeaux ; *IFPRI, Washington*) et a fait l'objet d'une publication dans la *Revue Économique* (**Berthoumieu et Bouët, 2016**).

firme du Nord a choisi son niveau optimal de R&D, les deux firmes se concurrencent et maximisent leur profit en fonction du résultat de la R&D. Nous considérons deux types de concurrence : Cournot (sur les quantités produites) et Bertrand (sur les prix). Nous vérifions ainsi si les résultats tiennent avec un changement de mode de concurrence.

Nous étudions l'impact de la mise en place de deux types d'instrument politique par le gouvernement du pays du Nord sur l'investissement en R&D de la firme du Nord. Nous intégrons des instruments mis en place au niveau des frontières (*"at-the-border" policy instruments*) : un tarif sur importations, des restrictions quantitatives (quota et restrictions volontaires aux exportations) et un prix-minimum. Nous intégrons des instruments mis en place derrière les frontières (*"behind-the-border" policy instruments*) : une subvention de la production et une subvention de la R&D. Pour cibler l'impact de ces instruments sur la R&D, il faut étudier celui sur le différentiel de profit mentionné précédemment. Dans ce chapitre, nous considérons que le gouvernement du Sud reste en « libre-échange » et ne met pas en place d'instrument politique. En effet, nous justifions les instruments politiques mis en place par le Nord par le fait que le gouvernement cherche à mettre en place des outils stimulant l'innovation pour palier au désavantage compétitif vis-à-vis de la firme du Sud. L'intégration d'instruments politiques mis en place par le Sud laisserait la place à une autre problématique.

Les résultats montrent que chaque instrument politique augmente le niveau de R&D de la firme du Nord mis à part les restrictions quantitatives. La mise en place de ces instruments entraine un transfert de profit de la firme du Sud vers la firme du Nord (*profit-shifting*). Ce transfert de profit est d'autant plus important que le coût marginal de la firme du Nord est faible. La firme du Nord est incitée à augmenter son investissement en R&D afin d'augmenter la probabilité de réussite de cet investissement. Néanmoins, l'analyse de l'impact de la mise en place d'un quota sur importations fait figure de cas particulier. Nous distinguons deux cas de figure : la mise en place d'un quota relativement restrictif et celle d'un quota très restrictif. Dans le premier cas, il s'agit d'un quota tel qu'il ne soit restrictif qu'en cas d'échec de la R&D. Un quota engendre une hausse du profit de la firme domestique car la concurrence de la firme étrangère diminue. Ici, le profit de la firme du Nord n'augmente qu'en cas d'échec de la R&D. Dans ce cas, la firme du Nord réduit son investissement en R&D par rapport à la situation de libre-échange. Dans le second cas, le quota est restrictif quel que soit le résultat de la R&D. La mise en place du quota peut alors soit augmenter soit diminuer l'investissement en R&D de la firme du Nord. Nous démontrons d'ailleurs qu'il existe un seuil tel que l'investissement en R&D soit exactement égal à celui de libre-échange. L'investissement en R&D devient plus fort qu'en libre-échange avec un quota plus restrictif que ce seuil. Il est intéressant de voir la différence qu'il peut y avoir entre la mise en place d'un quota et celle d'un tarif sur importations alors que chacun engendre une baisse des importations domestiques. Cela provient du fait que le quota engendre un changement dans la relation stratégique entre les firmes contrairement à un tarif (**Bhagwati, 1968** ; **Krishna, 1989**). Avec un quota restrictif, la firme du Nord bénéficie d'un avantage informationnel car elle connait déjà le volume maximum que peut exporter la firme du Sud (qui est fixé par le gouvernement). En concurrence de type Cournot, la firme du Sud n'exporte plus le volume optimal vers le pays du Nord. La firme du Nord choisit bien le niveau optimal de vente locale mais sans tenir compte de la condition de premier ordre de la firme du Sud. Les résultats sont robustes au type de concurrence (Cournot ou Bertrand).

Nous effectuons également une analyse de bien-être afin de vérifier que le gouvernement du Nord ait bien un intérêt à mettre en place chaque instrument politique. Cela permet également de déterminer quel est l'instrument favori du gouvernement du Nord. Pour cela, nous posons une fonction de bien-être national espéré du pays du Nord qui est la somme du profit espéré de la firme du Nord, du surplus du consommateur espéré et des recettes publiques espérées dans le pays du Nord. Les résultats montrent que chacun des instruments étudiés augmentent le bien-être national espéré du pays du Nord. Avec une concurrence de type Cournot, l'instrument favori est une subvention de la production. Malgré le coût en termes de dépenses publiques, elle permet d'augmenter fortement le profit espéré de la firme du Nord via un soutien direct (des recettes directes) mais aussi le surplus du consommateur en réduisant les prix. Avec une concurrence de type Bertrand, l'instrument favori devient le tarif sur les importations. Il permet d'augmenter le profit espéré de la firme du Nord et de créer des recettes publiques supplémentaires malgré une baisse du surplus du consommateur espéré. L'effet l'emporte sur celui de la subvention à la production. En effet, la concurrence de type Bertrand est plus concurrentielle que celle de type Cournot. Une subvention de la production réduit les niveaux de prix de manière trop importante ce qui stimule fortement la demande pour le produit vendu par la firme du Nord. De ce fait, les dépenses publiques sont relativement importantes ce qui pèse sur l'effet total positif sur le bien-être espéré du Nord.

CHAPITRE 2 – Différentiation Verticale, Incertitude, Recherche et Développement de Produit et Instruments Politiques dans un duopole Nord-Sud[2]

Le Chapitre 1 illustrait un investissement en R&D de procédés qui était réducteur de coûts. Nous nous intéressons maintenant à la R&D de produit. Comme nous l'avons dit précédemment, l'objectif de cet investissement n'est pas de réduire les coûts de production mais de différentier les caractéristiques du produit final par rapport à ceux des concurrents. Nous nous focalisons sur la différentiation verticale : l'investissement en R&D est supposé augmenter la qualité du produit.

Nous reprenons la même structure Nord-Sud que dans le Chapitre 1. Ce cadre théorique est déjà utilisé dans la littérature économique, même au niveau des innovations de produit (**Park, 2001** ; **Zhou, Spencer et Vertinsky, 2002**) : les firmes des pays riches sont considérées comme *high-tech* alors que les firmes des pays en développement sont considérées comme *low-tech*. Seule la firme du Nord investit en R&D. L'objectif étant de vendre un produit de plus haute qualité que celui de la firme du Sud. De la même manière, le résultat de la R&D est incertain : il peut se solder par une réussite ou un échec. En cas de réussite, il y a effectivement différentiation verticale entre les deux produits. La principale modification intervient au niveau des fonctions de demande : chaque consommateur a un plus fort intérêt pour le produit de la firme du Nord. En cas d'échec, les deux produits sont de qualité identique. La firme du Nord cherche donc à maximiser une espérance de profit du fait de l'incertitude. Elle choisit donc le niveau d'investissement en R&D optimal. Dans un second temps, les firmes se concurrencent sur les prix qu'elles fixent. Nous faisons donc l'hypothèse d'une concurrence de type Bertrand. Nous effectuons la même hypothèse de rendements décroissants de la R&D. De ce fait, l'investissement en R&D d'équilibre est une fonction croissante d'un différentiel de profit de la firme du Nord, comme dans le Chapitre 1. Il s'agit de la différence entre le profit en cas de réussite de la R&D, c'est-à-dire en présence de différentiation verticale, et celui en cas d'échec de la R&D. Nous analysons l'impact de la mise en place des mêmes instruments politiques que ceux du Chapitre 1. De la même manière, seul le gouvernement du Nord met en place ces instruments. Néanmoins, nous intégrons un instrument supplémentaire : un standard de qualité. Il s'agit d'un instrument technique mis en place par le gouvernement du Nord tel que seuls les produits de haute qualité puissent être vendus sur le marché du Nord. Il s'agit alors d'une forme de quota prohibitif.

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[2] Ce chapitre a été coécrit avec la doctorante Viola Lamani (LAREFI, Université de Bordeaux) et a fait l'objet d'un *LAREFI Working Paper* (**Berthoumieu et Lamani, 2016**).

Les résultats sont proches de ceux du Chapitre 1. Chaque instrument politique augmente l'investissement en R&D mis à part le quota sur importations. Un changement important concerne tout de même l'impact d'une subvention de la production dont la démonstration aboutit à un résultat qui n'est pas certain. Une explication potentielle est la suivante. La subvention de la production est le seul instrument qui engendre une baisse relativement forte des prix fixés par la firme du Nord. Ils diminuent plus fortement que ceux de la firme du Sud. La subvention contribue à augmenter les ventes locales et les exportations de la firme du Nord, de manière plus importante qu'un tarif par exemple. Comme nous l'avons dit précédemment, la principale caractéristique de la différentiation verticale est de modifier les fonctions de demande. Avec une subvention de la production, étant donné la hausse relativement forte de la demande pour le produit de la firme du Nord, l'incitation à différentier le produit verticalement peut être moins forte. Dans le chapitre précédent, le principal effet de la réussite de la R&D concernait une baisse du coût marginal de production. Ceci peut expliquer la différence au niveau de l'impact de la subvention de la production. Néanmoins, dans ce Chapitre 2, en effectuant des simulations numériques et en faisant varier les paramètres du modèle, nous obtenons systématiquement un effet positif de la mise en place de la subvention de la production sur l'investissement en R&D de la firme du Nord.

Nous effectuons une analyse de bien-être à l'aide de simulations numériques. La fonction de bien-être du pays du Nord est la même que dans le chapitre précédent. L'instrument préféré du gouvernement du Nord est systématiquement le tarif sur importations. Il s'agit potentiellement du seul instrument pouvant augmenter toutes les composantes du bien-être national. Un résultat important est que le surplus du consommateur espéré peut augmenter avec la mise en place du tarif alors que, paradoxalement, les prix fixés augmentent. Cela provient du goût du consommateur pour la qualité. Le tarif augmente l'investissement en R&D et ainsi la probabilité de réussite de la R&D. Il y a donc une plus forte probabilité que le bien produit par la firme du Nord soit de plus haute qualité. Si le consommateur est très sensible à la qualité, l'effet sur son surplus peut devenir positif. Nous identifions des cas de figure où il augmente, en utilisant des simulations numériques. Nous identifions également des cas de figure où un prix-minimum et un standard de qualité peuvent augmenter le surplus du consommateur. Mais ces deux instruments précédents ne créent pas de recettes publiques supplémentaires, ce qui explique que le tarif est préférable en termes de bien-être.

CHAPITRE 3 – Instruments Politiques, Brevets et Diffusion Internationale de la Technologie dans un Duopole Nord-Sud[3]

Nous étudions maintenant la question de la diffusion technologique. Il s'agit d'un sujet central permettant de stimuler le développement économique. Les modèles de croissance endogène ont montré que l'acquisition de technologies modernes permet d'augmenter le revenu par tête via la productivité des facteurs de production. Le niveau de vie des pays en développement peut ainsi être amélioré. Les conditions de travail peuvent également devenir plus favorables.

La diffusion de la technologie provient de la diffusion de l'information (**Geroski, 2000** ; **Keller, 2002**). Les nouveaux outils de télécommunication ont un rôle important. Comme nous l'avons présenté précédemment, il y a d'autres canaux de diffusion technologique entre pays : le commerce, les IDE et les *spillovers* de R&D. Il s'agit d'un phénomène qui ne peut pas être évité mais simplement accéléré ou ralenti. La diffusion de la technologie est très importante pour les pays du Sud. Il s'agit de la principale source d'acquisition de technologies modernes puisque le niveau des innovations locales reste faible (**Keller, 2004**). La protection industrielle des inventeurs/innovateurs de pays riches peut poser problème. Les inventeurs de certaines technologies peuvent déposer un brevet afin de disposer d'un monopole sur son utilisation. Le brevet peut être un frein à la diffusion technologique vers les pays du Sud.

L'objet du chapitre est de modéliser le phénomène de diffusion de la technologie d'une firme d'un pays du Nord vers une firme d'un pays du Sud. Il s'agit d'une diffusion inter-firme illustrée à l'aide d'une structure dynamique contrairement aux deux premiers chapitres. Nous nous inspirons du modèle de **Miyagiwa et Ohno (1997)** qui adaptent celui de **Spencer et Brander (1983)** en dynamique. Dans leur étude, initialement, deux firmes disposent d'une technologie obsolète et investissent en R&D pour découvrir une technologie nouvelle. Il y a une course à la R&D à la fin de laquelle il y a un vainqueur qui est la firme qui a découvert la nouvelle technologie la première. La seconde firme continue d'investir en R&D jusqu'à la découverte de la nouvelle technologie également. Il y a donc une période de monopole pour la première firme quant à l'utilisation de la nouvelle technologie.

Dans ce chapitre, nous considérons directement une situation asymétrique dès la période 0. La firme du Nord dispose d'une technologie nouvelle alors que la firme du Sud dispose d'une technologie obsolète. La diffusion de cette nouvelle technologie a lieu à une date T qui se situe sur l'intervalle $[0, \infty)$. La firme du Nord publie un brevet sur sa nouvelle technologie dans le but d'augmenter la durée de monopole de l'utilisation de la nouvelle technologie. La mise en place du brevet a un effet positif sur le profit actualisé de la firme du Nord en augmentant la durée de monopole. Mais en même temps, il y a un coût de publication et de maintenance du brevet. À chaque période de temps, la firme doit payer des frais de maintenance pour que le brevet reste en vigueur. De ce fait, il existe une durée totale de brevet optimale qui maximise le profit actualisé de la firme du Nord. La durée du brevet est également appelée « longueur du brevet » (*patent length*). Ainsi, lorsque la durée du brevet augmente, la diffusion de la nouvelle technologie entre la firme du Nord et celle du Sud ralentit. La firme du Nord choisit d'abord la durée optimale du brevet maximisant le profit actualisé. Puis, les deux firmes se concurrencent sur les quantités produites à chaque point de temps.

Nous étudions l'impact d'instruments politiques sur la vitesse de la diffusion de la nouvelle technologie de la firme du Nord vers la firme du Sud via l'effet sur la durée du brevet. Cette fois-ci

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[3] Ce chapitre a fait l'objet d'une publication dans la revue *The International Trade Journal* (**Berthoumieu, 2016**).

nous intégrons non seulement des instruments mis en place par le pays du Nord, mais aussi par la suite des instruments mis en place par le gouvernement du Sud en guise de première extension. Dans les deux premiers chapitres, la problématique centrale était de connaitre les moyens dont disposent les décideurs politiques pour relancer les innovations des pays du Nord face à la concurrence croissante des pays à bas coûts de production. Ici, la problématique est de connaitre l'impact des instruments politiques sur la diffusion vers les pays du Sud. Il y a un enjeu en termes de développement pour les pays du Sud. Il peut être intéressant d'intégrer la mise en place de représailles de ce fait. De plus, nous considérons la mise en place d'un instrument politique supplémentaire de la part de la firme du Sud : un investissement public en R&D. En effet, les niveaux de R&D sont faibles dans les pays en développement. Ce programme public de R&D permet à la firme du Sud d'utiliser une technologie intermédiaire située entre la technologie obsolète et la technologie nouvelle.

Les résultats montrent que les instruments mis en place par le gouvernement du Nord ont tendance à ralentir la diffusion de la nouvelle technologie en incitant la firme du Nord à augmenter la durée du brevet. Une nouvelle fois, le quota sur importations fait exception à la règle. Sa mise en place incite à réduire la durée du brevet et ainsi à accélérer la diffusion de la nouvelle technologie, et ce quel que soit son degré de restriction cette fois-ci. Les instruments mis en place par le gouvernement du Sud accélèrent la diffusion de manière générale. L'investissement public en R&D décourage la firme du Nord à augmenter la durée du brevet car le différentiel en termes de dotation technologique est moins important.

Il est intéressant d'analyser l'impact total de la mise en place de tarifs ou encore de subventions à la production de la part des deux gouvernements. Ces situations renvoient au concept de « guerre commerciale » (*trade war*) lorsque deux pays mettent en place des instruments protectionnistes. Les résultats montrent qu'une guerre commerciale sur les subventions à la production ralentit la diffusion de la technologie alors qu'une guerre tarifaire l'accélère. Cela provient de la nature de ces instruments. La subvention à la production du gouvernement du Nord entraine un gain direct via des recettes supplémentaires sur le profit de la firme du Nord alors que le tarif n'entraine qu'un gain indirect via la baisse de la concurrence du Sud. La subvention du Sud entraine un coût indirect pour la firme du Nord alors que le tarif du Sud entraine un coût direct. Ainsi, avec les deux subventions, la firme du Nord est incitée à augmenter la durée du brevet, alors qu'avec les deux tarifs, elle est incitée à la réduire.

Au niveau de l'analyse de bien-être, l'instrument favori du gouvernement du Nord est la subvention à la production. Elle augmente le profit actualisé de la firme du Nord et le surplus du consommateur. Elle augmente aussi la durée du brevet ce qui augmente le coût total de celui-ci. Ce coût est reversé par la firme du Nord à l'office nationale des brevets du pays du Nord c'est-à-dire aux pouvoirs publics de ce pays. Cela limite l'effet négatif de la subvention sur les recettes publiques. L'instrument favori du gouvernement du Sud est l'investissement public en R&D. Il s'agit d'un moyen de disposer d'une technologie intermédiaire rapidement ce qui profite à la firme du Sud et aux consommateurs.

CHAPITRE 4 – Diffusion de la Technologie via Collaborations de Brevet : Le Cas de l'Intégration Européenne[4]

Ce chapitre propose une approche empirique de la question des déterminants de la diffusion technologique entre pays du Nord et pays du Sud à l'aide d'estimations économétriques. Pour ce faire, il est nécessaire d'utiliser un instrument qui puisse mesurer au mieux la variable expliquée de l'étude, en l'occurrence la diffusion technologique. Suite à une revue des méthodes utilisées dans la littérature économique, nous avons fait le choix de retenir comme indicateur les collaborations internationales de brevets (**Fleming et al., 2007** ; **Breschi et Lissoni, 2009** ; **Picci, 2010** ; **Guan et Chen, 2012** ; **Montobbio et Sterzi, 2013**). Il s'agit de brevets publiés dans un pays par un inventeur avec la collaboration d'un inventeur localisé dans un pays étranger.

Nous nous intéressons au cas particulier de l'Union Européenne. Nous étudions les collaborations de brevets entre les pays d'Europe de l'Est ayant ou non récemment intégré l'Union Européenne et ceux d'Europe de l'Ouest, les pays à l'origine de la construction européenne. Nous utilisons les données sur les brevets publiés à l'Office Européenne des Brevets (*European Patent Office*) par des inventeurs d'Europe de l'Est ayant collaboré avec des inventeurs d'Europe de l'Ouest. Nous utilisons des données fournies par l'OCDE (*OECD*) en prenant 13 pays émergents d'Europe de l'Est – dont 8 membres de l'Union Européenne depuis 2004 (République Tchèque, Estonie, Lituanie, Lettonie, Hongrie, Pologne, Slovaquie et Slovénie), 2 membres depuis 2007 (Roumanie et Bulgarie) et 3 non membres (Russie, Ukraine et Croatie) – et 7 pays riches d'Europe de l'Ouest sur la période 2000-2011.

Nous étudions l'impact de plusieurs variables explicatives potentielles. Nous cherchons, en particulier, à analyser l'impact de l'intégration européenne des pays émergents d'Europe de l'Est. Il s'agit d'une variable muette (*dummy variable*) prenant la valeur 1 si le pays est membre de l'Union Européenne et 0, sinon. Nous cherchons également à illustrer l'impact : (i) de la taille des marchés avec les niveaux de PIB et de population ; (ii) du capital humain avec les dépenses en R&D et en éducation ; (iii) des relations commerciales et des localisations ; (iv) des inégalités de revenu et de technologie entre les pays. Cela reprend globalement les différentes variables intégrées dans la littérature économique. Ainsi, nous analysons l'impact d'autres variables telles que l'existence de frontière commune entre les deux pays, les niveaux de PIB, les inégalités internationales de revenu entre les pays, les niveaux de population, la distance géographique, la distance technologique (aussi bien au niveau de la structure des innovations que de l'intensité des innovations), les dépenses en R&D, les dépenses publiques dans l'éducation, les flux commerciaux et les Investissements Directs Étrangers.

Au niveau de la variable expliquée, nous effectuons une analyse en deux temps. Dans un premier temps, nous analysons l'impact de chaque variable explicative sur la probabilité qu'il y ait collaboration de brevet entre le pays émergent d'Europe de l'Est et le pays riche d'Europe de l'Ouest. Dans un second temps, nous étudions l'impact sur l'intensité des collaborations de brevet, autrement dit leur nombre. Il s'agit donc d'une approche en deux temps que l'on trouve essentiellement dans les études empiriques de commerce international utilisant des équations de gravité. Nous étudions à la fois la marge extensive (probabilité) et la marge intensive (intensité). Il s'agit du principal apport de cette étude puisque l'essentiel des études sur les collaborations de brevet se focalisent sur la marge intensive. Concernant l'analyse sur la probabilité, nous effectuons une estimation de type Logit puisque la variable expliquée est dite muette. Pour l'analyse de l'intensité, nous effectuons une estimation de type Poisson mais aussi une estimation conditionnelle en Moindres Carrés Ordinaires et Généralisés.

[4] Ce chapitre a fait l'objet d'un *LAREFI Working Paper* (**Berthoumieu, 2015**).

Les résultats montrent que l'intégration européenne ne semble pas être un déterminant significatif de la probabilité de collaboration de brevet puisque le coefficient n'est pas significativement différent de zéro avec les différentes régressions effectuées. En revanche, l'effet sur l'intensité des collaborations de brevet est significatif et positif. Le coefficient est généralement situé entre 0,2 et 0,3. Le fait d'appartenir à l'Union Européenne pour les pays d'Europe de l'Est augmente d'environ 0,2/0,3% l'intensité de leurs collaborations technologiques avec les pays d'Europe de l'Ouest. L'intégration européenne n'est donc pas un facteur de probabilité mais plutôt d'intensité des collaborations de brevet. Nous effectuons un test de robustesse en prenant le nombre d'années depuis que le pays est membre de l'Union Européenne (jusqu'en 2011). La valeur est comprise entre 0 et 8 puisque les premières intégrations à l'Union Européenne ont eu lieu en 2004 pour ces pays. Les résultats sont identiques en termes de signe et d'effets significatifs mais les coefficients deviennent plus faibles. Ils sont régulièrement inférieurs à 0,1.

Au niveau des autres déterminants significatifs, il y a l'impact significatif et positif des exportations des pays d'Europe de l'Est en direction de ceux de l'ouest, aussi bien sur la probabilité que l'intensité. En contrepartie, les importations et les IDE n'ont jamais d'effet significatif. La distance géographique est également un déterminant significatif mais dont l'effet est négatif : les pays ont moins de chance de collaborer et collaborent moins lorsqu'ils sont éloignés géographiquement. Les inégalités de revenu ont un effet significativement négatif sur la probabilité de collaboration alors que la distance technologique (en termes de structure et d'intensité) pèse significativement sur l'intensité des collaborations.

CHAPITRE 5 – Conclusion Générale

Ce travail consiste à apporter un certain nombre d'éléments de réponse aux questions posées à la fin de l'introduction générale. L'objectif n'était pas d'identifier la supériorité du protectionnisme ou du libre-échange au niveau des innovations et de la diffusion de la technologie. Il n'est pas possible de proposer une conclusion générale : (i) il existe plusieurs types de barrières protectionnistes dont l'impact n'est pas forcément identique ; (ii) leur effet peut être incertain ou du moins conditionné par certains paramètres.

Nous sommes parvenus à démontrer que les pays industrialisés ayant des problèmes de compétitivité face à la concurrence croissante des pays émergents ont un intérêt à mettre en place certains instruments de politique commerciale. Ceux-ci peuvent potentiellement stimuler les innovations mesurées par les dépenses en R&D. En effet, la mise en place d'un tarif sur importations, d'une subvention à la production, d'une subvention à la R&D et d'un prix-minimum de la part du gouvernement du Nord permet d'augmenter l'investissement en R&D de la firme domestique. En effet, ces instruments entrainent un transfert de profit de la firme du Sud vers la firme du Nord (du fait du soutien des pouvoirs publics). La firme du Nord est incitée à augmenter son investissement en R&D pour que le gain de profit soit plus fort. Ces résultats tiennent que l'on raisonne avec de la R&D de procédé ou de la R&D de produit.

Ce travail nous a permis également d'illustrer la particularité d'un instrument politique. Il s'agit des restrictions quantitatives. En effet, la mise en place d'un quota, contrairement aux autres instruments, a un effet ambigu sur l'investissement en R&D domestique. Nous avons vu qu'il pouvait y avoir deux types de quota : un quota relativement restrictif et un quota très restrictif. Avec le premier, sa mise en place entraine une baisse de la R&D de manière certaine. Avec le second, il existe un seuil tel que le niveau de R&D est le même qu'en libre-échange. Avec un quota plus restrictif, le niveau de R&D augmente par rapport au libre-échange. Inversement avec un quota moins restrictif. Cet instrument peut décourager l'innovation. Cela provient de la nature même du quota. Comme l'expliquent **Bhagwati (1968)** ou encore **Krishna (1989)**, le quota modifie la relation stratégique existante entre deux firmes concurrentes. Le résultat permet d'expliquer pourquoi les pays du Sud peuvent être incités à mettre en place des Restrictions Volontaires aux Exportations, dans la mesure où elles réduisent la R&D.

Nous étudions également la question de la diffusion technologique, dans une structure théorique dans un premier temps. Si certains pays du Sud bénéficient d'avantages en termes de coût du travail bon marché, en contrepartie, ils peuvent subir un désavantage en termes de dotation technologique. La diffusion de la technologie permet aux pays du Sud de disposer de technologies modernes découvertes dans les pays du Nord. Nous étudions un cas de figure où un brevet est déposé sur cette découverte afin de ralentir la diffusion de la technologie. Nous avons analysé l'impact des instruments politiques sur la durée de ce brevet qui mesure la vitesse de la diffusion technologique. Les instruments mis en place par le gouvernement du Nord ralentissent la diffusion de la technologie en augmentant la durée du brevet mis à part le quota sur importations une nouvelle fois.

Enfin, nous proposons une analyse empirique au niveau de ce concept de diffusion technologique à l'aide d'une étude économétrique. La diffusion de la technologie est mesurée par les collaborations de brevet entre les pays riches d'Europe de l'Ouest et les économies en transition de l'Est. Nous étudions en particulier l'impact de l'intégration européenne des pays d'Europe de l'Est au cours des années 2000 sur la diffusion de la technologie. Cela ne semble pas être un déterminant significatif de la probabilité de collaboration entre les pays. En revanche, cela augmente significativement l'intensité (le nombre) de ces collaborations. Nous avons également analysé l'impact d'autres déterminants potentiels.

Enfin, nous pouvons avancer un certain nombre d'extensions potentielles au niveau des différentes études réalisées dans ce travail.

- Une première extension potentielle est l'intégration de représailles du gouvernement du Sud dans les chapitres théoriques même si nous proposons une première possibilité d'extension à la fin du Chapitre 3. Celle-ci demeure largement perfectible. Une analyse de bien-être avec la mise en place d'instruments à la fois dans le Nord et dans le sud pourrait être intéressante.
- Il serait également possible d'utiliser un cadre théorique différent pour ces chapitres. Nous nous concentrons sur des duopoles. Il serait intéressant de modéliser un oligopole à N firmes dans chaque pays, d'intégrer d'autres pays, ou encore de modifier ces structures Nord-Sud en structures Nord-Nord ou Sud-Sud.
- L'introduction de l'asymétrie d'information peut être envisagée, notamment concernant les deux premiers chapitres. Nous pouvons considérer un cas de figure où le gouvernement du Nord ne connait pas la probabilité de succès de la R&D ou le niveau de coût marginal en cas de succès.
- Concernant le Chapitre 3, la principale extension serait d'introduire la mise en place d'un contrat de licence (*licensing*) entre la firme du Nord et la firme du Sud afin que la seconde puisse utiliser la nouvelle technologie plus rapidement. Ainsi, la rapidité de la diffusion de la technologie dépendrait essentiellement de la date de la mise en place de ce contrat de licence.
- Au niveau de l'étude économétrique du Chapitre 4, une possibilité d'extension serait d'utiliser une autre variable expliquée que les collaborations de brevet pour mesurer la diffusion de la technologie, notamment en disposant de données sur les IDE en R&D en provenance des pays riches et en direction des pays du Sud. Il serait également bénéfique d'intégrer de véritables variables d'instruments politiques puisque l'intégration à l'Union Européenne n'est pas seulement une mesure de libre-échange.

-CHAPTER 0-

General Introduction

Technology has a significant impact on economic behavior. Households consume high technology goods and services in order to increase their welfare and to be part of the digital world. Producers benefit from modern technologies in order to reduce production costs and to produce innovative goods and services. From a macroeconomic point of view, countries also benefit from technological innovations in order to increase total productivity and economic growth, and to involve job creations. Nevertheless, they may also involve unskilled job destructions.

0.1. Technology and Competitiveness

The issue of technological innovations is crucial in economics. They condition the access to new high quality goods and services for consumers. They also impact producers' competitiveness that we can define as the ability to sell their product when they face world competition. There are two forms of competitiveness: price-competitiveness and non-price competitiveness. We can define price-competitiveness as the ability to sell products with almost identical features compared to competitors' products, but at a lower price. Technological innovations may increase price-competitiveness when they are "cost-reducing" i.e. when they reduce production costs. We can define non-price competitiveness as the ability to sell products that are differentiated vertically in terms of features, at the same price as that of competitors. For example, product quality may be higher. Technological innovations may also increase non-price competitiveness since they may influence features of goods and services. The relationship between innovations and competitiveness is a crucial issue especially for countries where competitiveness influences economic and trade performances. The French case is a good example because France has faced external deficits since 2002. France has experienced a downturn and still pains to recover. During the same period, Germany has benefitted from external surpluses. Policy makers often put forward the difference in terms of labor cost. However, in 2012, the labor cost per hour worked in the industrial sector equaled EUR 36.30 in France and EUR 35.20 in Germany (Source: DESTATIS). The difference is higher for the non-wage labor cost, i.e. for social security contributions. In 2012, for a wage of EUR 100, such a cost equaled EUR 50 in France and EUR 27 in Germany. Therefore, labor cost is not the only determinant of competitiveness.

The role of innovations may be significant. Research and Development (R&D) expenditures measure producers' technological innovations. We can define R&D as a *"systematic activity combining both basic and applied research, and aimed at discovering solutions to problems or creating new goods and knowledge* [Source: Business Dictionary]*."* R&D expenditures are both public and private. Firms invest in human capital in order to improve economic and trade performances. There are two types of R&D: product R&D and process R&D. Product R&D aims to create new products and to differentiate finished goods vertically compared to competitors' goods. Process R&D aims to create new processes such as modern equipment in order to reduce production costs.

Process R&D is cost-reducing R&D. Does Germany innovate more than France? In 2012, the share of R&D expenditures in the Gross Domestic Product (GDP) equaled 2.92 percent in Germany and 2.26 percent in France (Source: World Bank World Development Indicators). Therefore, German firms innovate more. It explains the difference in terms of non-price competitiveness between the two countries. The quality of German goods is often higher.

Competitiveness issues do not only relate to the competition between rich countries. Developed countries are facing growing competition from developing/emerging economies. In this study, "Northern countries" are industrialized/developed countries and "Southern countries" are developing/emerging countries. They aim to sell their product on big Northern markets. Developing economies benefit from lower production costs owing to a cheaper labor force. For example, in 2012, the labor cost per hour worked in the industrial sector only equaled EUR 3.80 in Romania (source: DESTATIS). Therefore, developed countries like France and Germany face a competitive disadvantage. Nevertheless, production costs also depend on other variables like labor productivity, capital cost and infrastructure quality.

The share of emerging countries' exports in the total level of exports has increased compared to that of rich countries'. In 2012, the share of developed countries' exports of commodities equaled 51.81 percent, while, in 1995, such a share equaled 71.55 percent (**WTO, 2014**). The same evolution has occurred for the production of wealth. In 2012, the share of high-income OECD countries' GDP in the world GDP equaled 61.29 percent, while the same share equaled 80.61 percent in 1995 (Source: World Bank WDI). Rich countries are looking for ways to increase their economic and trade performances compared to emerging countries. Innovations may be considered as the solution since they increase competitiveness while competition from the South is growing. Even if rich countries have a competitive disadvantage in terms of labor cost, they benefit from an advantage in terms of technological endowment. Most of R&D investments are implemented in developed countries. The share of Southern countries' R&D expenditures in their GDP has always been lower than 2 percent (Source: World Bank WDI).

0.2. International Technology Diffusion

There is a high correlation between innovations and competitiveness. Industrial protection and technology diffusion are also crucial issues. An inventor that creates a new technology or a new product benefits from a temporary monopoly on the use of the new technology or the sale of the new product. We call it a "monopoly period" for the inventor. The speed of technology diffusion depends on such a period and on the ability of competitors to innovate by investing in R&D. But emerging countries' R&D expenditures are low. They wait to benefit from spillovers from rich countries' innovations rather than innovate themselves. *"For the most part, the South does not initiate technical change* [**Stewart, 1984**, p. 88]*."* Previously, we have mentioned the impact of innovations on competitiveness for rich countries while competition from emerging countries is growing. But technology diffusion relates to economic, social and human development issues for Southern countries.

Technology diffusion increases economic development via a supply effect. Firms may benefit from modern processes and produce new finished goods. It leads to further revenues for countries that benefit from foreign technologies. Emerging economies have to modernize capital endowments and finished goods in order to increase non-price competitiveness. For example, the pharmaceutical industry is essentially composed of developed countries' Multinational Firms (MNF). In 2014, the top 10 of pharmaceutical firms by prescription sales contains Swiss, US, British and French MNF (source: Pharmaceutical Executive).[5] They locate in each region of the world. Producers from Southern countries are trying to emerge on international markets. The most significant example is Indian firms. They specialize in generic drugs by producing a fifth of the world output (Source: World Health Organization). They sell a high share of their output in Southern countries.

Technology diffusion also influences human development. The diffusion of modern technologies improves working conditions for the labor force. It involves a welfare gain for households. But skilled labor replaces unskilled labor. As a result, unskilled labor's welfare may decrease with technology diffusion. The main gain is the diffusion of new products and new varieties that satisfy new needs. It also improves the level of knowledge (with information technology), education and health (with better living conditions and medical care). Therefore, technology diffusion may increase development indicators.

Finally, technology diffusion may change emerging countries' societies. According to the stages of economic growth in **Rostow (1959)**, new processes for producers and new products for consumers involve the transition to the *"drive to maturity"* (fourth stage) and to the *"age of high mass consumption"* (fifth stage).

Technology diffusion is not something avoidable, except for less advanced countries that face a structural gap. The real issue is to study the speed of technology diffusion from the North to the South. Countries may implement policy instruments to accelerate or slow down technology diffusion.

0.3. Implementation of Policy Instruments

We focus on two potential issues: the relationship between technological innovations and competitiveness in rich countries, and the speed of technology diffusion toward developing/emerging countries. Another issue is to study the impact of policy instruments implemented by policy makers on both the innovations incentive and the speed of technology diffusion. Examples of policy instruments are trade policies. Trade policy can be defined as the implementation or the removal of instruments that protect local producers and disadvantage foreign competitors. Free trade is a particular case in which a government phases out all trade barriers. In this case, trade policy relates to protectionism. In our study, we define "free trade" as the case in which governments do not implement any policy instrument.

[5] See the article "Pharma Exec's pharma top 50 in Brief" in Pharmaceutical Executive (July 2, 2014).

Governments may implement traditional policy instruments like import tariffs and import quotas. There are two forms of tariffs: ad-valorem and specific. An ad-valorem tariff can be defined as a percentage of the value of imports paid by foreign exporters to the government. A specific tariff can be defined as an amount paid by foreign exporters to the government in local currency for one unit of imports. Under both cases, foreign exporters have to pay a tax to the government. A tariff also disadvantages local consumers by increasing the level of price of imports. The winners of the implementation of an import tariff are the government that benefits from tariff revenues and the local producers that benefit from a higher market share due to a drop in the foreign competition. Nevertheless, countries set bound tariffs at the World Trade Organization (WTO) such as the level of applied tariffs cannot be higher.

An import quota can be defined as the maximum level of imports from a foreign country. Foreign exporters' sales decrease as compared to free trade. The government may provide import licenses via bids. Therefore, an import quota may involve further public revenues. The losers and winners are the same as those with tariffs. These instruments are traditional forms of protectionism i.e. defensive protectionist barriers. They are implemented "at-the-border" in order to disadvantage foreign competition.

Other policy instruments like subsidies may also be implemented. A subsidy can be defined as a support to domestic producers. According to the WTO, *"a subsidy shall be deemed to exist if: (a) (1) there is a financial contribution by a government or any public body within the territory of a member … or (a) (2) there is any form of income or price support … and (b) a benefit is thereby conferred* [Source: Article 1.1 of the WTO's Agreement on Subsidies and Countervailing Measures]*."* There are also two forms of subsidies: ad-valorem subsidies and specific subsidies. There are also several types of subsidy.

First, governments may implement production/export subsidies. They provide revenues for each unity of output/export. Nevertheless, the WTO prohibits export subsidies because they cause trade distortions (Source: Article 3 of the WTO's Agreement on Subsidies and Countervailing Measures). The WTO does not prohibit production subsidies but a member can complain to the WTO's Dispute Settlement Body (DSB) about their trade-distorting effect. For example, governments may disguise production subsidies by subsidizing job creations in order to escape the regulation of the WTO. Second, governments may also implement investment subsidies like R&D subsidies. The WTO does not prohibit such instruments because they do not directly involve trade distortions.

Each type of subsidy aims to reduce domestic firms' costs. As a consequence, it increases consumer surplus by reducing prices and increasing domestic producers' output. Foreign firms' sales decrease with respect to domestic firms'. Domestic public revenues also decrease. Subsidies are offensive trade barriers compared to tariffs and quotas. They are implemented "behind-the-border". Subsidized firms benefit from a direct increase in their profit.

Governments may also implement new trade policy instruments like Voluntary Export Restraints (VER), export taxes and price undertaking. VER are implemented by exporting countries. They set a maximum level of exports for their domestic producers. Generally, such an instrument is implemented due to pressures from importing countries. In this case, it corresponds to a disguised quota that the WTO cannot prohibit. The most significant example is the "Multi Fibre Arrangement" in 1974. Asian countries have limited their exports to Europe. Such an arrangement ended in 2005.

Exporting countries can also implement export taxes. A particular motivation is an improvement in their terms-of-trade by increasing the price of exports at the expense of their competitiveness. Southern countries often implement such export taxes on agricultural goods like corn and soy.

Governments may also implement price undertaking by setting a minimum price such as foreign firms cannot sell at a lower price. Northern government implements such minimum prices on imports from Southern countries where production costs are lower. In 2013, the European Union implemented a minimum price on solar panels imports from China. With these instruments, the winners are domestic producers and the losers are both foreign exporters and domestic consumers owing to the increase in prices.

Finally, governments can implement informal barriers i.e. disguised protectionist barriers. They do not directly influence the level of trade. Sanitary and Phytosanitary measures (SPS) and Technical Barriers to Trade (TBT) like industrial standards are good examples. In a report for the G8 Summit, **Evenett (2013)** focuses on "*Protectionism's Quiet Return*." Traditional forms of protectionism only represent less than 40 percent of the measures implemented since the crisis of 2008. According to him, 431 protectionist measures have been adopted throughout the world between June 2012 and May 2013. Only 95 of them were different forms of subsidy and 64 were increases in tariff. Informal barriers cannot be defined as direct trade policy instruments. But, since they reduce the level of trade, they are new forms of protectionism that escape the WTO's regulation.

0.4. A Review of the Economic Literature

First, we review the economic literature on trade policy instruments. Then, we focus on studies on technological innovation and diffusion.

0.4.1. Policy Instruments

Since this thesis is part of a study on the economic impact of several policy instruments like trade policies, let us review the economic literature on this type of instruments. Such a review enables us to know how the implementation of these instruments impacts strategic variables like output, profits and welfares.

The issue of the implementation of trade policies has already been studied in the economic literature. According to **Orgün (2012)**, *"trade policy is one of the oldest subject areas in economics* [p. 1283]*."* First, studies have illustrated that free trade is better than protectionism. For example, **Ricardo (1817)** proves that free trade is better than autarky because countries are encouraged to specialize in industries in which comparative advantages are high and to import goods in other industries. Trade barriers are non-optimal.

The first argument in favor of protectionism is mentioned by **List (1841)**. He introduces the "infant-industry argument" by explaining that trade barriers promote new industries. Such barriers may be removed when new industries drive to maturity. Protectionism leads to free trade in this case. **Mikic (1998)** agrees with the infant-industry argument by explaining that policy makers should help new firms against distortions like the imperfect access to information and capital.

Bickerdike (1906) illustrates the positive impact of the implementation of an import tariff with the "big country argument." With a small country, such an import tariff reduces the national welfare by creating production and consumption distortions. But the country size matters. A big country benefits from a monopoly (monopsony) power by representing a significant share of the world supply (demand). An import tariff significantly reduces the national demand, and therefore, the world demand. Therefore, it increases the domestic price, reduces the world price and improves the terms-of-trade. The impact on the national welfare may become positive. The terms-of-trade effect does not work for small countries.

During the 1980s, new trade theories studied the issue of the strategic trade policy. They introduced assumptions of imperfect competition and increasing returns to scale. **Spencer and Brander (2008)** define the strategic trade policy as a *"trade policy that affects the outcome of strategic interactions between firms in an actual potential international oligopoly* [p. 1]*."*

Brander and Spencer (1985) analyze the implementation of export subsidies in a theoretical framework close to the Boeing-Airbus duopoly in the aircraft industry. After its market entry, Airbus benefitted from subsidies implemented by the European Union. This economic support allowed Airbus to stay on the market. In return, the US government retaliated by subsidizing Boeing. Under the Nash equilibrium, authors prove that each government is encouraged to implement a positive export subsidy even if the foreign government retaliates. **Eaton and Grossman (1986)** criticize such a result because it depends on the mode of competition on the market. **Brander and Spencer (1985)** use output competition i.e. Cournot competition. Such a mode of competition relates to the aircraft industry in which firms compete in deliveries. According to **Eaton and Grossman (1986)**, under price competition i.e. Bertrand competition, governments may be encouraged to implement export taxes. **Brander and Spencer (1985)** also demonstrate that cooperating governments are encouraged to tax domestic exports in order to maximize cumulative welfares. The reason is that taxes involve an increase in prices, terms-of-trade and public revenues. **Brander and Spencer (1984)** study the impact of an import tariff under imperfect competition by comparing cooperative and non-cooperative equilibria. The world welfare does not increase with a non-cooperative tariff. But the effect may be positive with a cooperative tariff especially in the case of high transport costs.

Krugman (1984) introduces the role of consumers' taste for diversity when firms produce differentiated goods. He studies the impact of an import tariff in a theoretical framework under monopolistic competition. The tariff increases foreign firms' production costs. Domestic (foreign) firm's output, market share and profit increases (decreases) with the tariff. **Lancaster (1984)** also studies the impact of an import tariff by considering consumers' taste for variety. Each consumer has one most preferred variety. The tariff increases the price of imported goods, reduces the price of domestic goods, and increases the number of varieties for consumers. With retaliations, when countries export identical featured goods ("*interleaved case*"), tariffs increase the number of varieties. If they export different featured goods ("*split case*"), such a number decreases.

The main difference between traditional and new trade theories is that trade policy instruments promote exports. Domestic firms are encouraged to enter foreign markets. Policy instruments involve a profit-shifting from foreign firms to domestic firms (**Brander, 1986**; **Spencer, 1986**; **Brander, 1995**; **Neary and Leahy, 2000**). **Baldwin and Krugman (1988)** use the example of the aircraft industry. They show that a subsidy for Airbus would involve a high gain for world consumers. The subsidy would increase third countries' welfare.

Spencer (1986) mentions that governments should subsidize strategic sectors i.e. *"key industries."* A key industry has the following features: (i) the profit gain must be higher than the cost of the subsidy; (ii) a highly concentrated oligopoly market in order to face foreign competition; (iii) there are high barriers to entry; (iv) a high international competition; (v) it benefits from competitive advantage relative to foreign competition, from scale economies, and from learning effects; (vi) there is a minimum (maximum) of spillovers from domestic (foreign) firms to foreign (domestic) firms; (vii) a product subsidy should be implemented at the beginning of the lifecycle; (viii) the subsidy does not reduce the productive efficiency by increasing the total production cost (**Kreinin, 1995**). **Neary and Leahy (2000)** design a theoretical framework and mention three reasons to implement trade policies: (i) the profit-shifting from foreign firms to domestic firms; (ii) the changes in domestic firms' behavior with respect to foreign firms; (iii) the changes in domestic firm's behavior with respect to governments' future policies.

Several studies criticize these previous results. **Dixit (1984)** designs a model with a rich country and a developing country. He studies the impact of a tariff implemented by the developing country. The tariff may reduce the number of varieties with a high elasticity of substitution between each country's exported goods. These results question those of **Lancaster (1984)**. **Krugman (1987)** mentions that there are three main limits of the new interventionism: (i) empirical difficulties to model imperfect competition markets; (ii) dissipated gains with new entries on the market; (iii) robustness of the results with general equilibrium models. **Baldwin and Green (1988)** find that the implementation of protectionist barriers does not increase the level of output for five US industries over 1972-1982.

Rodrik (1988) studies the potential impact of several developing countries' liberalization. He studies the case in which Turkey implements free entry in automobile, tire and electrical appliances industries. It would increase Turkey's national welfare under each case. **Kalt (1988)** studies the case in which trade barriers are implemented on the United States-Canada bilateral trade in the timber industry. The United States consume a high share of Canadian timber and benefit from a monopsony power. An import tariff implemented by the US government would increase (reduce) the US (Canadian) welfare. But an export tax implemented by the Canadian government would reduce the US welfare, while the Canadian welfare would increase owing to further public revenues. Each policy instrument would reduce the cumulative welfare of both countries. Finally, considering that each instrument is implemented, the effect on welfares would be negative. **Dick (1994)** makes an empirical study for 213 commodities in the United States in 1970. The implementation of an import tariff in these industries does not significantly increase US exports. **Bhagwati (1994)** argues in favor of free trade in spite of the negative impact on unskilled labor. But fair trade is another crucial issue for producers.

Rodrik (1995) illustrates the relative success of the implementation of export subsidies via several examples. There are two examples of success: South Korea during the 1970s and Brazil during the 1980s. Subsidies increased automobile exports in these countries. However, there are two examples of failure: Bolivia and Kenya during the 1980s. Subsidies increased the level of corruption. Finally, there are two intermediary examples: India during the 1960s and Turkey during the 1980s. Export subsidies increased exports but they also involved corporate-related abuses in terms of price. Domestic firms did not reduce their prices. The author mentions *"the dilemma of the weak state"* defined as the difficulty for governments to encourage domestic firms to increase their exports by implementing subsidies and to avoid abuses. According to **Bagwell and Staiger (1999)**, a non-cooperative trade policy that aims to increase the terms-of-trade is not efficient. Conversely, a trade agreement on reciprocity and nondiscrimination may be efficient.

Grossman and Helpman (1994) integrate political aspects. Lobbies may influence governments' trade policies. *"Organized industries"* i.e. lobbies are protected by import tariffs and benefit from export subsidies. However, *"non-organized industries"* do not benefit from such supports. Therefore, *"special-interest groups"* benefit from trade policies at the expense of other industries. The authors also show that an increase in the size of the lobby leads to a drop in the governmental support. Free trade is optimal when all voters represent one lobby.

Other limits of policy instruments are trade disputes and trade wars among countries. Each Government implements trade policies because the other does the same thing. There is a dilemma of prisoners. A non-cooperative equilibrium appears. Governments maintain policy instruments in force while free trade is optimal for maximizing the cooperative cumulative welfare (**Baldwin and Krugman, 1986**; **Brander, 1986**; **Staiger, 1995**). Tariff wars generally lead to welfare losses. But the effect may become positive. It depends on the price-elasticity of imports (**Johnson, 1953**) and on the nature of exported and imported goods (**Kennan et Riezman, 1988**). **Irwin (1998)** studies the specific example of the US Smoot-Hawley tariff implemented in the 1930s while European countries retaliated. He designs a general equilibrium model. Such a tariff reduced US imports. But exports also decreased. Furthermore, the level of unemployment sharply increased while the tariff was supposed to protect the labor factor. The Smoot-Hawley tariff reduced the US national welfare. **Crucini and Kahn (2003)** use the same framework and show that such a tariff involved a sharp drop in the US output, consumption and investment.

0.4.2. Innovations

The first studies on the role of innovations are those of the liberal trend in the 18th century. Authors have considered that innovations are the only way for an economy to leave the *"steady-state"* equilibrium. Innovations lead to the growth of productivity and production. **Smith (1776)** explains the role of innovations in terms of labor organization by introducing the *"division of labor"* based on the specialization of workers who perform specific tasks. **Ricardo (1817)** extends such a topic by introducing the *"international division of labor"* with the specialization at the international scale. This is a first vision of the international fragmentation of the production process in the 20th century. **Malthus (1798)** mentions that countries stay in a steady-state of poverty called a "Malthusian catastrophe" because the growth of population is generally higher than that of subsistence. The only way to leave such a steady-state situation for a country is to innovate in order to increase agricultural crops.

Schumpeter (1942) studies the role of several forms of innovation: for example, product innovations, process innovations, and organization innovations. He introduces the concept of *"innovation clusters."* A major innovation involves further innovations. He mentions the crucial role of entrepreneurship as the main source of innovation and productivity in a country that may increase workers' wage. Nevertheless, he also introduces the concept of *"creative destruction."* Innovations also involve the destruction of the oldest structures of the economy.

R&D Expenditures

During the 1980s, the economic literature started to study the economic impact of R&D expenditures, especially cost-reducing R&D. The main motivation of these analyses was that *"firms perceive strategic considerations beyond the simple desire to minimize total costs* [**Brander and Spencer, 1983**, p. 225]*."*

The first studies have designed partial equilibrium theoretical models under R&D competition. There are two traditional modes of competition: Cournot (output) and Bertrand (price). For example, under Cournot competition, firms select the optimal level of output that maximizes their profit. Under R&D competition, they select the optimal level of R&D. **Dasgupta and Stiglitz (1980)** show that firms invest more in R&D under R&D competition compared to Cournot competition.

Brander and Spencer (1983) design an international duopoly with R&D competition. They show that firms overinvest in R&D. Such an overinvestment involves a loss of productive efficiency. The conclusion of the study illustrates a paradox. The authors make the assumption of cost-reducing R&D. The marginal cost decreases with the R&D investment. In the same time, firms do not minimize their total production cost which increases compared to Cournot competition. The reason is that R&D investments encourage firms to increase their output. Therefore, firms' profits decrease compared to Cournot competition. Nevertheless, other studies prove that R&D overinvestment may not be theoretically and empirically viable (**Griliches, 1992**; **Jones and Williams, 1998**; **Jones and Williams, 2000**).

Dixit (1984) illustrates the impact of innovations in a North-South theoretical model by considering a cost-reducing investment. Income inequalities between the two countries decrease in the case of high *"elasticities of substitution in variable and fixed costs [p. 114]."* The fixed cost depends on the size of plants while the variable cost depends on the labor force. In this case, elasticities of substitution illustrate that there is a relationship between the quantity of labor and the size of plants. The previous result is a paradox because the economic vulnerability of Southern countries increases with the level of the elasticity of substitution. Furthermore, innovations may reduce the Southern country's terms-of-trade for commodities. But the number of varieties increases (decreases) in the Southern (Northern) country. The effect of innovations on the Southern country's welfare is positive with a high level for the elasticity of substitution. **Romer (1986)** studies the impact of R&D expenditures (via the human capital) on the growth of the Total Factor Productivity (TFP) in an oligopoly with N firms. Human capital involves increasing returns. This study illustrates the positive correlation between R&D and productivity.

Empirical studies have also analyzed the impact of R&D on the economic environment. **Griliches (1980)** studies the potential causal link between the evolution of R&D and productivity for 39 US industries over 1959-1977. The drop in R&D expenditures may have explained the drop in productivity in the US in the 1960s. **Griliches (1986)** implements an empirical study on the impact of 1000 firms' R&D expenditures over 1957-1977 on their productivity, value added, profit, and revenues. The effect on productivity is positive. The effect is higher with private-funded R&D investments compared to public funding. The effect on revenues, value added, and profit is also positive. **Hall and Mairesse (1995)** study the impact of 351 French firms' R&D capital over 1980-1987. The effect is significantly positive on the value added per worker and on the total factor productivity. **Audretsch and Feldman (1996)** study the impact of R&D expenditures on the difference in value added between the states of the United States in 1982. There is a significant positive impact. **Griffith, Redding and Van Reenen (2004)** design a wide study on the relationship between productivity and R&D for 12 OECD countries over 1974-1990. They find a positive and significant correlation. R&D may also reduce the technological gap among countries. **Ang and Madsen (2011)** also find a positive impact of R&D expenditures on productivity for the specific case of the Asian miracle economies (Japan, South Korea, China, India, Singapore and Taiwan) over 1953-2006 by designing an endogenous growth model. Asian firms' productivity has increased with both R&D cooperation and R&D competition for several industries like high-tech and industrial equipment (**Fukao et al., 2011**).

The economic literature has also focused on the impact of firm size on R&D investments (**Symeonidis, 1996**). The first studies illustrate a positive correlation (**Schumpeter, 1942**; **Galbraith, 1957**). **Scherer (1984)** finds such a positive correlation for US firms in 1974. But the positive correlation is not significant in all studies. **Bound et al. (1984)** find that the correlation is, first, negative, and then, positive. **Levin, Cohen and**

Mowery (1985) find opposite results. At first, an increase in the concentration of firms leads to an increase in their R&D expenditures. Then, these expenditures decrease. **Cohen, Levin, and Mowery (1987)** demonstrate that firm size does not significantly influence the intensity of R&D investments with an empirical analysis. But firm size seems to increase the probability of R&D investment. **Pavitt et al. (1987)** find that the correlation may depend on the type of industry for British firms over 1945-1983. Innovations are higher for firms with more than 50,000 employees. But for industries like machinery and electricity, small firms are innovative. **Acs and Audretsch (1987)** find a negative correlation between firm size and innovations for US firms. The main problem with such a result is that firm size may be endogenous and may depend on R&D expenditures (**Scherer, 1992**).

Considering these previous results, it seems complex to conclude to a positive or negative correlation. **Cohen, Nelson and Walsh (2002)** mention the crucial impact of public research like academic research on industrial research. There is a positive correlation. Furthermore, firm size significantly increases the share of private R&D projects that collaborate with public research. Several studies criticize the result that illustrates a positive correlation between firm size and R&D expenditures. Size is a simple proxy (**Bottazi et al., 2010**).

Other factors are also mentioned. There is a positive correlation between R&D expenditures and internal resources control (**Barney, 1991**; **Galende and Suarez, 1999**). These internal resources are: financial resources (**Kim and Park, 2012**), profitability (**Coad and Rao, 2010**), human resources (**Fleming, 2001**), intellectual property with patent filings (**Arora, Ceccagnoli and Cohen, 2008**), export ability (**Wakelin, 1998**), and firm size. **Lai, Lin and Lin (2015)** verify whether or not these positive relationships hold for Japan, South Korea and Taiwan in 2011. The results generally hold except for the impacts of financial resources for Japan, profitability for Japan and Korea, and human capital for Taiwan.

The economic literature has also studied the issue of firms' R&D cooperation. **Veugelers (1998)** reviews these studies. R&D cooperation is generally measured by Research Joint Ventures. **D'Aspremont and Jacquemin (1988)** design a theoretical duopoly with partial equilibrium and analyze the impact of R&D cooperation. They find that R&D cooperation with strong spillovers involves an increase in R&D investments, output, profits and national welfares. Other studies find the same results (**De Bondt and Veugelers, 1991**; **Motta, 1992**; **Leahy and Neary, 1997**).

Kamien, Muller and Zang (1992) introduce two types of cooperation: R&D Joint Ventures and R&D Cartels. Under R&D Joint Ventures, firms share the R&D gain but may select their own level of R&D. Under R&D Cartels, firms select the optimal level of R&D that maximizes their cumulative profit. **Qiu and Tao (1998)** also consider two types of R&D cooperation: coordination and cooperation. Under coordination, firms aim to reduce R&D overinvestment in order to increase productive efficiency. Under collaboration, they share profit gains from R&D cooperation. An R&D subsidy may not reduce the foreign firm's R&D investment under collaboration while the effect is always negative under coordination. The economic literature also mentions the risk of cheating with R&D Joint Ventures. Even if cooperation may be optimal, when firms implement R&D Joint Ventures, they may dissimulate their level of R&D (**Shapiro and Willig, 1990**; **Kesteloot and Veugelers, 1994**).

Dynamic studies on R&D cooperation have been implemented (**Martin, 2002**; **Miyagiwa and Ohno, 2002**; **Cellini and Lambertini, 2009**). Firms often cooperate on process innovations rather than product innovations. According to **Miyagiwa and Ohno (2002)**, R&D expenditures increase with R&D cooperation and strong spillovers. Empirical studies have also been implemented. **Fritsch and Franke (2004)** study the potential relationship between R&D cooperation, spillovers and innovations for 1,800 firms from three German regions. Differences between regions show that spillovers intensity may be a significant determinant of innovations. But the effect of R&D cooperation on spillovers and innovations is low.

Policy Instruments and R&D

The theoretical economic literature studies the impact of trade policy instruments on R&D expenditures. **Spencer and Brander (1983)** analyze the impact of the implementation of an R&D subsidy by the domestic government while the foreign government is not policy active. The results show that the R&D subsidy increases (reduces) the domestic (foreign) firm's R&D expenditures. It also increases (reduces) the domestic (foreign) country's national welfare. Nevertheless, if the domestic government also implements a production subsidy, it is encouraged to tax R&D expenditures. **Leahy and Neary (1997)** show that a government that subsidizes the domestic firm's production may be encouraged to subsidize R&D expenditures when domestic and foreign firms cooperate. The government is not encouraged to subsidize R&D expenditures, otherwise. **Krugman (1984)** show that the implementation of an import tariff increases (reduces) the domestic (foreign) firm's R&D expenditures.

Several studies analyze the difference between an import tariff and an import quota. A quota changes the strategic relationship among firms (**Bhagwati, 1968**; **Krishna, 1989**). **Reitzes (1991)** analyzes such policy instruments in a duopoly. An import tariff increases the domestic firm's R&D investment while an import quota reduces it. Firms are encouraged to reduce their R&D expenditures with a quota because the level of competition decreases. **Costa Cabral, Kujal and Petrakis (1998)** design a theoretical model in which two firms select their optimal cost-reducing R&D investment and, then, compete in prices (Bertrand competition). The domestic (foreign) firm's R&D decreases (increases) with the implementation of a quota close to the free trade level. Authors mention that these results differ from the "infant industry" argument. **Bouët (2001)** finds the same difference between a tariff and a Voluntary Export Restraint (VER). The main contribution is that the author introduces uncertainty in the model. He designs a North-South duopoly. The Southern firm benefits from a lower labor cost. The Northern firm faces competition from the Southern firm on the Northern market. The Northern firm invests in R&D owing to a competitive disadvantage. The Southern firm does not invest in R&D. The success of the Northern firm's R&D investment is uncertain. There is a probability of R&D success.

A share of the economic literature also studies the difference between the impact of direct supports to firms like subsidies and that of indirect instruments like tax cuts and tax credits. **David, Hall and Toole (2000)** design a microeconomic structure and show that both direct supports and tax cuts increase R&D expenditures. Tax credits also increase R&D expenditures. **Hall and Van Reenen (2000)** review the economic literature and mention the positive relationship for US firms (**Mansfield, 1986**; **Berger, 1993**; **Hall, 1993**), Canadian firms (**Mansfield and Switzer, 1985**; **Bernstein, 1986**), Swedish firms (**Mansfield, 1986**) and nine OECD countries (**Bloom et al., 2002**).

Carvalho (2011) mentions some advantages and disadvantages for direct and indirect instruments. Direct supports allow governments to select and to implement investment projects by subsidizing firms. But such instruments are really costly. Indirect instruments allow firms to select their own investment projects. The cost is lower for governments. Nevertheless, the impact may be lower for firms that benefit from high levels of profit.

A lot of studies mention the positive impact of direct instruments on R&D expenditures (**Levy and Terleckyj, 1983**; **Lichtenberg, 1987**; **Falk, 2006**; **Shin, 2006**). Some studies mention a negative impact (**Levy, 1990**; **Montmartin, 2013**). The studies of indirect instruments also illustrate opposite results. **Montmartin (2013)** shows that indirect instruments increase (reduce) R&D expenditures in the short-run (long-run). According to the author, direct and indirect supports are substitutes.

Product Innovations and Vertical Differentiation

Product R&D influences features of finished goods such as quality and involves vertical differentiation. **Mussa and Rosen (1978)** design an important model with product R&D and product quality. They compare the levels of quality under two market structures: monopoly and competition. The main conclusion is that producers sell less quality goods under monopoly compared to competition. Such a result explains why the negative effect of the monopoly on the consumer surplus increases with the taste for quality. Prices are also higher under monopoly. **Shaked and Sutton (1982)** also study the choice of quality in a theoretical model. First, firms set the optimal level of quality. Then, they select the optimal level of price. Under duopoly, firms select different levels of quality. They select the same level when the number of firms is greater than two.

As it has been shown empirically, firms invest in both product and process R&D (**Capon et al., 1992**; **Landau and Rosenberg, 1992**). Studies show that firms invest in product R&D at the beginning of a product's lifecycle and invest in process R&D at the end (**Utterback and Abernathy, 1975**; **Klepper, 1996**). Product R&D expenditures are particularly high in high-tech industries like automobile and electricity (**Scherer and Ross, 1990**; **Fritsch and Meschede; 2001**; **Park, 2001**; **Toshimitsu, 2003**; **Chenavaz, 2011** ; **Jinji and Toshimitsu, 2013**).

The theoretical economic literature also studies the case of vertical differentiation with an asymmetric framework with a high-tech firm from a rich country and a low-tech firm from a developing country (**Das and Donnenfeld, 1989**; **Park, 2001**; **Zhou, Spencer and Vertinsky, 2002**; **Moraga-Gonzalez and Viaene, 2005**; **Ishii, 2014**).

Park (2001) designs a model in which each firm sells its finished good in a third country. The level of quality depends on R&D expenditures. The author shows that the government of the developing (rich) country is encouraged to subsidize (tax) its domestic firm's R&D expenditures under Bertrand competition, but to tax (subsidize) such expenditures under Cournot competition. Therefore, the results depend on the mode of competition. **Zhou, Spencer and Vertinsky (2002)** find the same results. Nevertheless, empirical examples of R&D taxes are really scarce (**Audretsch and Yamawaki, 1988**; **Gabriele, 2002**; **Impullitti, 2010**). **Ishii (2014)** also designs a model in which firms invest in product R&D and export their goods to a third market. He studies the impact of R&D subsidies implemented by each government. The results illustrate that the intensity of quality-price competition increases (decreases) with the developing (developed) country's subsidy.

0.4.3. Technology Diffusion

Keller (2004) reviews measures and determinants of technology diffusion in the economic literature. One primary determinant of technology diffusion is R&D investment owing to R&D spillovers. Innovations measured by R&D expenditures lead to technology diffusion measured by R&D spillovers.

The speed of technology diffusion between two countries also increases with the volume of bilateral trade (**Rivera-Batiz and Romer, 1991**; **Grossman and Helpman, 1991**; **Eaton and Kortum, 2002**). The bilateral trade in intermediate goods is a significant determinant. Developing countries import intermediate goods from developed countries and need to use modern technology to produce finished goods. Usually, international trade involves information flows among countries due to business interactions. **Coe and Helpman (1995)** design an empirical study and find the same results. The R&D spillovers effect increases with the openness of international trade. The role of "learning-by-exporting" is also mentioned in several studies (**Rhee, Ross-Larson and Pursell, 1984**; **Clerides, Lach and Tybout, 1998**; **Bernard and Jensen, 1999**; **Keller, 2004**; **Keller, 2010**).

The speed of technology diffusion between two countries also increases with the Foreign Direct Investments (FDI) stock owing to FDI spillovers (**Griliches and Hausman, 1986**; **Keller, 2002**; **Griffith, Redding and Simpson, 2003**; **Keller, 2010**). For example, Japanese R&D investments in Asian developing economies increased nine-fold from 1993 to 2007 (**UNCTAD, 2011**). Developing countries like China, Korea and India benefited from these Japanese investments. Multinational Firms (MNF) locate in foreign countries and hire the local labor force. Spillovers among countries appear due to worker training put forward by MNF (**Aitken and Harrisson, 1999**; **Fosfuri, Motta and Rønde, 2001**). This is the reason why the relationship between MNF and subsidiaries located in foreign countries clearly influences FDI (**Markusen, 2002**).

International trade and FDI represent two important factors of technology diffusion. **Ethier and Markusen (1996)** design a dynamic theoretical framework with technological externalities and study the choice between international trade and FDI for a firm that wishes to sell its product in a foreign country. A firm from the domestic country creates a new product and benefits from a temporary monopoly (equal to two periods in the model). Firms from the foreign country do not invest in research in order to discover new products. The domestic firm has a choice between exporting from its domestic country and locating a part of its output in the foreign country. According to the authors, localization involves greater absorption of information for other firms in the foreign country. Technology diffusion seems to be faster with localization than with exports. But it represents a cost for the domestic firm because the new product is no longer in a monopoly situation. The choice between exporting and locating depends on the transport cost of exports and the monopoly rent of localization.

The economic literature analyzes the impact of public policies (especially trade policies) on technology diffusion. **Cheng (1987)** designs a framework close to **Spencer and Brander (1983)** within a dynamic model. Considering international technology diffusion, he shows that the R&D subsidy that only satisfies the domestic interest may benefit from the foreign firm. It may also enhance diffusion. **Grossman and Helpman (1991)** implement a theoretical macroeconomic model with technological spillovers and study the economic impact of trade openness for a small country. They show that trade policies that reduce (promote) international trade, especially trade in intermediate goods, like tariffs and quotas (subsidies) have a negative (positive) effect on innovations and technology diffusion via knowledge spillovers. For example, a tariff cut involves an increase in trade volume, trade through variety of intermediate goods and stock of human capital through variety. Spillovers to foreign countries are greater. **Miyagiwa and Ohno (1997)** design a dynamic theoretical model and analyze the impact of subsidies on R&D and welfare. Initially, two firms use an old technology. At each point in time, they invest in R&D to discover a new technology. There is a likelihood of discovering it at each point in time for each firm. When one firm discovers the new technology, it no longer invests in R&D. But the other firm continues to invest until it also discovers the new technology. The former firm benefits from an exogenous monopoly period with the new technology that corresponds to the speed of diffusion.

Reppelin-Hill (1999) makes an econometric study of the relationship between the trade openness and the speed of clean technology diffusion by using the example of the steel industry. He demonstrates that clean technology diffusion is *"faster in countries that have more open trade policy regimes* [p. 284]." **Geroski (2000)** reviews some determinants of technology diffusion. Information diffusion involves technology diffusion. He suggests that governments subsidize technological externalities *"to promote … communication … and to motivate them* [p. 621]." **Van Dijk and Szirmai (2006)** show a preponderant role of industrial policies on technology diffusion in the case of Indonesian paper-making machinery over 1923-2000. Policies like import-substituting industrialization over 1974-1984 or export-oriented industrialization over 1984-1997 involved an increase in technology diffusion. **Battisti (2008)** also uses the example of the environment and establishes that technology diffusion is a slow process. Governments' policies may increase R&D investment but *"should also look at the adoption and the extent of use of innovations because that is the place where the generation of the benefits from inventions takes place* [p. 528]." **Bustos (2011)** shows that the MERCOSUR integration of Argentina involved a technological upgrading of domestic firms because free trade may accelerate the adoption of new technologies and increase the productivity.

The economic literature also studies the impact of other variables that influence the speed of technology diffusion. Geographic distance between two countries has an impact on technology diffusion because of its effect on bilateral trade. Generally, previous studies have proven that technology diffusion is faster within one country than between two countries (**Jaffe, Trajtenberg and Henderson, 1993**; **Eaton and Kortum, 1999**; **Branstetter, 2001**). There is a border effect. Nevertheless, **Irwin and Klenow (1994)** find that the speed of technology diffusion did not significantly differ for US firms compared to foreign firms in the semi-conductor industry from 1974 to 1992. Other papers study the significant negative effect of the distance in kilometers on the speed of technology diffusion (**Keller, 2002**; **Bottazi and Peri, 2003**).

Furthermore, there is a high correlation between technology diffusion and industrial protection. For example, patents impact diffusion because they protect information and technological endowment for firms. A patent may slow down technology diffusion by giving a product or process monopoly to firms from developed countries. However, citing patents may be a measure of technology diffusion. **Eaton and Kortum (1999)** consider that patent filings in a foreign country represent another (imperfect) measure. They prove that diffusion depends on the ability to file patents in the foreign country and on the level of patent filing costs. **Pakes (1986)** also mentions the role of patent costs when agents want to maintain the patent in force.

The economic literature has also designed models with patents by studying the impact on national welfare. Such patents may involve monopoly rents for patentees. They may also encourage innovations because firms have to discover new processes or new products. One section of the literature considers that competitors' imitations are never a threat and finds that policy makers select an optimal finite patent length (**Nordhaus, 1969**; **Scherer, 1972**). Another section considers that imitations are costless and introduces patent length and breadth (**Tandon, 1982**; **Klemperer, 1990**; **Gilbert and Shapiro, 1990**). According to **Gilbert and Shapiro (1990)**, patent breadth cannot be clearly defined: *"a broader patent allows the innovator to earn a higher flow rate of profit during the lifetime of the patent* [p. 107]*."* Even if patent breadth leads to deadweight loss, they demonstrate that the optimal patent length is infinite because it minimizes social costs. **Gallini (1992)** introduces an endogenous imitation cost by considering *"the ability of competitors to invent around* [p. 52]*."* He finds that the optimal patent length is short in order to avoid imitation. Such a result contradicts previous studies. **Futagami and Iwaisako (2007)** design a theoretical endogenous growth model in which innovators file patent on new goods. They determine the optimal patent length that maximizes households' social welfare. They show that the social welfare decreases with an infinite patent length compared to a finite patent length.

Mathew and Mukherjee (2014) study the impact of the patent regime on inward FDI in a North-South structure. The incentive of Northern firms' FDI in the Southern country increases with a strong patent regime, especially when the costs of Southern innovations are high. A strong patent regime is a case in which only the patent holder can sell its product. Here, the impact of the patent regime on the technology diffusion is ambiguous because it may increase FDI inwards in the Southern country, but it may also increase the monopoly period for Northern firms relative to the sales of new products

The economic literature has also studied the case of patent collaborations. They are a potential measure of technology diffusion for collaborations between developed and emerging countries. For example, social network structures influence knowledge flows and actors' performances (**Cowan and Jonard, 2004**; **Schilling and Phelps, 2007**). **Fleming et al. (2007)** prove that patent collaborations enhance productivity by considering regional small-world structures defined as *"cohesive clusters connected by occasional nonlocal ties* [p. 938]*."* **Guan and Chen (2012)** show that non OECD members improved their technological performances with collaborations with OECD members. **Breschi and Lissoni (2009)** study the relationship between geography and knowledge diffusion by illustrating that co-invention networks depend on the fact that researchers are not likely to relocate.

The economic literature also uses gravity equations to find potential determinants of technological collaborations. Technological distance, common language and common border are significant determinants (**Guellec and Van Pottelsberghe de la Potterie, 2001**; **Picci, 2010**). **Maggioni, Nosvelli and Uberti (2007)** find a significant and negative impact of geographical and technological distances for 109 European regions over 1998-2002. **Montobbio and Sterzi (2013)** study the specific case of emerging countries. They find a negative and significant effect of geographic distance and a positive and significant effect of technological proximity and common language. They also illustrate that stronger intellectual property rights increase international technological collaborations from multinational firms' subsidiaries. Nevertheless, we have to mention an important limit in using patent collaborations as the explained variable. According to **Bergek and Bruzelius (2010)**, patent collaboration statistics may be the result of simple inventor movements.

0.5. Presentation of the Study

This study aims to answer the following questions:

- Are firms from developed countries encouraged to innovate when their domestic government implements policy instruments?
- Do results hold with both process and product R&D?
- Do such policy instruments accelerate or slow down technology diffusion to emerging countries?
- What are the significant empirical determinants of technology diffusion?

Chapter 1 illustrates the study of the impact of policy instruments (import tariff, production subsidy, R&D subsidy, quota, VER and minimum price) on R&D expenditures in a North-South theoretical framework. We consider a duopoly with a firm from a Northern country and another from a Southern country. The Southern firm benefits from a competitive advantage with a lower labor cost. The Northern firm invests in process R&D in order to reduce its marginal cost. Here, R&D expenditures are cost-reducing. We introduce uncertainty. We set a probability that the Northern firm's R&D is successful and reduces its marginal cost. The results illustrate that each policy instrument increases the Northern firm's R&D investment except for the import quota.

Chapter 2 studies the impact of policy instruments on product R&D expenditures. We introduce vertical differentiation between goods by considering the same North-South duopoly. We analyze the impact of the same policy instruments as in Chapter 1 and of a quality standard. The results are generally the same.

Chapter 3 introduces technology diffusion via a dynamic theoretical model. We consider that the Northern firm benefits from a technological advantage. It uses a new technology while the Southern firm only uses an old technology. Furthermore, the Northern firm files a patent that slows down the new technology diffusion and selects the optimal patent length. We study the impact of policy instruments implemented by the North on the speed of the new technology diffusion through the impact on the patent length. Since the main issue of this chapter is Southern countries' economic development through technology diffusion, we also study the impact of policy instruments implemented by the South. The results show that policy instruments implemented by the North slow down the new technology diffusion except for the import quota. Policy instruments implemented by the South accelerate the new technology diffusion.

In these theoretical chapters, we use the same structure, even if the model is dynamic in Chapter 3. Despite the possibility of drawing criticism on the use of a similar model structure, we stand by our choice since our framework is operational and allows us to easily achieve clear and targeted results.

Chapter 4 makes an empirical study on potential determinants of technology diffusion. We analyze the impact of Eastern European countries' European Union integration on their patent collaborations with Western European countries. We run econometric estimations for 13 Eastern and 7 Western European countries over 2000-2011. We study the impact on both the probability and the intensity of patent collaborations. The main result is that the European Union integration does not significantly increase the probability of patent collaborations but does significantly increase the intensity of such collaborations.

-CHAPTER 1-

Policy Instruments, Cost-Reducing Research and Development, and Uncertainty in a North-South Duopoly[6]

1.1. Introduction

For many high-income countries, the issue of economic competitiveness in the face of growing globalization has been at the center of public debate for more than a decade. Competitiveness is an essential element of a country's market shares and exports, as well as its production and employment levels. Determining the right policies to improve the competitiveness of a sector is complex, especially in the context of globalization. In particular, there is much debate over how to ensure that the private industrial sector can compete with imports coming from countries with low production costs. As we have mentioned in the general introduction (Chapter 0), the technological dimension is a key issue because R&D expenditures can lead to either reduced production costs or increased product quality. In that sense, R&D may be one way in which high-income countries' private industrial sectors may react to growing competition from countries with lower production costs.

Consequently, it becomes crucial to determine whether a high-income country's government is in a position to support its domestic firms' R&D expenditures. The objective of this chapter is to evaluate the impact of various "behind-the-border" and "at-the-border" policy instruments on domestic firms' R&D. We also evaluate the impact of these instruments on other variables like domestic production and profits, consumer surplus, and public revenues. Finally, we conduct a welfare analysis. We focus on cost-reducing R&D investment in this chapter. R&D may be also undertaken with other objectives like the design of a new product (see Chapter 2).

The model that we develop is based on **Bouët (2001)** by introducing uncertainty in the impact of R&D in a simple way. Such an uncertainty makes the model more realistic, which is an advantage over **Spencer and Brander (1983)** and **Reitzes (1991)**. Moreover, this theoretical structure may be extended to Bertrand competition. A generalization to Bertrand competition is important. From its modeling features, this model is close to the broader set of strategic trade policy models. These models have been highly criticized for their lack of robustness, in particular the mode of competition.[7] Therefore, it is important to study the impact of the same policy instruments under both

[6] A French version of this chapter has been written with Antoine Bouët (LAREFI, University of Bordeaux; IFPRI, Washington) and published in *Revue Économique* (**Berthoumieu and Bouët, 2016**). An English version is available in an *IFPRI Discussion Paper* (**Berthoumieu and Bouët, 2015**).

[7] See **Brander and Spencer (1985)** where the optimal export subsidy is positive under Cournot competition, and **Eaton and Grossman (1986)** where it is negative under Bertrand competition. An export tax is optimal under the second case. Other modeling features are identical.

Cournot and Bertrand competitions. A criticism may be raised against this theoretical structure since it is a partial equilibrium model. In short, this partial equilibrium model is not able to draw any general equilibrium conclusion. However, we can consider small-sized industries. We can also argue that this theoretical structure is much more tractable than a general equilibrium model.

We use a North-South structure with a Northern firm and a Southern firm. The Southern country is an emerging country. Each firm produces in its domestic country. The South benefits from a competitive advantage with lower production costs. The Northern firm implements cost-reducing R&D expenditures in order to reduce its production costs. But the R&D outcome is uncertain. It may be successful. In this case, the Northern firm benefits from a low marginal cost. But it may also be unsuccessful. In this case, the marginal cost is high. The Southern firm's marginal cost is low. A possible interpretation is that it benefits from a lower labor cost. Therefore, the Southern firm does not invest in R&D. We set a probability that the Northern firm's marginal cost is low. Such a probability increases with the R&D investment.

We analyze the impact of six policy instruments implemented by the Northern government: (i) three "at-the-border" instruments (an import tariff, an import quota, and a minimum price); (ii) two "behind-the-border" instruments (a production subsidy and an R&D subsidy). Some of these effects have never been studied before in such a theoretical framework, specifically the quota, the minimum price and the production and R&D subsidies. While trade policy is traditionally understood as a set of policy instruments implemented "at-the-border" such as import tariffs, quotas, and VERs, we also study the impact of other barriers implemented "behind-the-border" such as production subsidies, R&D subsidies, public R&D investment and minimum prices.

These "behind-the-border" policies are typically implemented with the objective of benefiting domestic firms over foreign firms. R&D subsidies in particular are becoming more and more common. The European Union implemented programs of technological development support in the 1980s (**Luukkonen, 2000**). The economic literature has introduced the concept of additionality i.e. *"the difference which government-sponsored programs have made to the recipients, particularly companies, in terms of R&D activities* [**Luukkonen, 2000**, p. 711]*."* In 2013, the French government created a Public Investment Bank (*Banque Publique d'Investissement*) in charge of funding innovating firms.[8] Also in 2013, "Romi," a Brazilian firm, received a governmental loan of BRL 27 million with a below-market interest rate in order to invest in innovations.[9]

Another form of "behind-the-border" policy is the implementation of business clusters, initiated or even subsidized by governments. A business cluster is a geographic concentration of firms interconnected in a particular field. It is based on the model of **Porter (2000)**. In 2008, 71 business clusters (*Pôles de Compétitivité*) existed in France. They connect private companies with universities and private/public research centers.

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[8] See the article "Tailored funding with the Public Investment Bank" (December 5, 2013) by *France Diplomatie*, the official website of the French Ministry of Foreign Affairs.

[9] See the newspaper article "Protectionism: The hidden persuaders" in *The Economist* (October 10, 2013).

They have received USD 1.3 billion of public subsidies from 2005 to 2008. **Broekel et al. (2015)** study the case of the German biotechnology industry and show that *"firms in (technology) clusters as compared to outside firms are particularly prone to receive support from the 6th EU-Framework Programs* [p. 1441]." We also consider the implementation of a production subsidy. The WTO tries to prevent production subsidies because they may create trade distortions. However, governments can easily subsidize indirectly a domestic firm's production via tax cuts and employment subsidies. A good example of production subsidies is European agricultural subsidies with the Common Agricultural Policy (CAP). In 2014, the EU spends EUR 58 billion for agricultural subsidies (Source: Europa, European Commission Website).

We also consider the implementation of "at-the-border" policy instruments. We study the impact of an import tariff even if it represents a traditional form of policy instrument. Governments still implement non-null import tariffs. For example, in 2014, the Most Favored Nation (MNF) applied tariff equaled 5.3 percent for the EU (**WTO, ITC and UNCTAD, 2015**). We also include quantitative restrictions like quotas and VER. Currently, 11 quantitative restrictions barriers on imports are in force for the EU (Source: WTO, Non-Tariff Measures Database). Finally, we study the impact of a minimum price agreement on R&D, as well as on domestic profits, production, and consumer surplus. This type of agreement has recently been implemented in the European Union. In 2013, the European Commission set a minimum price on imports of solar panels from China. Just prior to this agreement, the European Commission threatened Chinese exporters with a 47.6 percent antidumping duty (Source: Europa, European Commission Website).

We conclude that each policy instrument increases the Northern firm's R&D investment except for an import quota. In this case, the Northern firm reduces R&D expenditures. Furthermore, each policy instrument always increases the Northern country's national welfare up to an optimal level except for the minimum price under several cases. These instruments often reduce the Southern country's national welfare. Under Cournot (Bertrand) competition, the Northern government's favorite policy instrument is the production subsidy (import tariff).

Section 1.2 presents the model under Cournot competition and Section 1.3 analyzes the impact of the six policy instruments under this mode of competition. After explaining how the model is modified under Bertrand competition, Section 1.4 analyzes the impact of four trade policy instruments under this alternate mode of competition. We discuss the results and we make a welfare analysis in Section 1.5. Section 1.6 concludes.

1.2. The Model under Cournot Competition

Consider a partial equilibrium model with two countries. There is competition between a firm from a Northern country and another from a Southern country. There are two segmented markets. Each firm sells one share of its output domestically and exports the other share to the foreign market.

The framework relates to an empirical example, for instance the automobile industry in which firms may innovate in terms of product and process. Firms export their finished good to foreign markets. The North-South duopoly works because Northern automobile firms face competition from Southern automobile firms. A significant example is Tata, an Indian firm which sells on its domestic market and exports to Northern markets. The firm operates *"in over 175 markets"* and has *"over 6,600 sales and service touch points* [Source: Tata Motors 69th Annual Report 2013-2014, p. 16]*."* The European Union represents an important market. Maruti Suzuki is another good example. Competition from Southern automobile firms is growing owing to lower production costs compared to Northern firms. The Indian market symmetrically represents a great opportunity for Northern automobile firms like Renault and Honda. For example, Renault sold 43,384 vehicles between January and April 2015 (Source: *The Economic Times*).[10] It also launched a new car model called "Kwid" for the Indian market on September 2015. Furthermore, the automobile industry is a good example because firms invest in both product and process R&D. Finally, we can legitimize the implementation of policy instruments. For example, in 2014, the European Union's ad-valorem import tariff equals 10 percent in the automobile industry (Source: MAcMap). Developed countries also implement import quotas in such an industry. The number of quantitative restrictions in force on imports in 2015 is 18 in Australia, 6 in Canada, 4 in the European Union, 12 in Japan, 8 in New-Zealand, and 7 in Switzerland (Source: WTO).

We denote by x_n (respectively, x_s) the Northern firm's domestic sales (respectively, exports to the Southern market), and y_s (respectively, y_n) the Southern firm's domestic sales (respectively, exports to the Northern market). We denote by X_n (X_s) the total supply on the Northern (Southern) market such as: $X_n = x_n + y_n$ ($X_s = x_s + y_s$). The Northern market price is denoted by p_n while the Southern market price is denoted by p_s. The Southern firm's marginal production cost is low while the Northern firm's marginal cost is low conditional to the success of an investment in R&D.

Assumption 1.1: There is a Cournot competition on both markets. Each firm selects the optimal levels of domestic sales and exports. Prices depend on quantities and are given by inverse demand functions: $p_i = p_i(X_i) = p_i(x_i + y_i), \forall i = \{n, s\}$. The price decreases with the total supply on each market: $p_i' = \mathrm{d}p_i(X_i)/\mathrm{d}X_i < 0, \forall i = \{n, s\}$.

Assumption 1.2: Each firm's production cost function is linear. Marginal production costs and unit transport costs are constant.

[10] See the article "10 notable facts about Indian automobile market" in *The Economic Times* (June 2, 2015).

Consider the following production cost functions:

$C(x_n + x_s) = c(x_n + x_s) + gx_s + F$

$C^*(y_n + x_s) = c^*(y_n + y_s) + g^*y_n + F^*$

where c (c^*) denotes the Northern (Southern) firm's constant marginal production cost and F (F^*) the Northern (Southern) firm's fixed cost. We introduce fixed costs in order to include increasing returns. We have: $c^* = c^l$, where c^l denotes the value of a low marginal cost.

The Northern firm invests in R&D. If such an R&D investment succeeds, its marginal cost is: $c = c^l$. If it does not succeed, its marginal cost is: $c = c^h$, with $c^h > c^l$, where c^h denotes the value of a high marginal cost.

We denote by g (g^*) the Northern (Southern) firm's unit transport cost. Introducing a transport cost is more credible for this model. Exports involve higher costs compared to domestic sales. Such a transport cost depends on the geographic distance between countries. We do not consider that R&D influences transport cost. Note that we could also have considered iceberg transport costs (**Samuelson, 1954**).

The Northern firm invests a level r of R&D, with a constant unit R&D cost denoted by v. We have:

$$\text{Prob}\left[(c = c^l)/r\right] = \alpha(r); \text{Prob}\left[(c = c^h)/r\right] = 1 - \alpha(r); 0 < \alpha < 1 \tag{1.1}$$

Assumption 1.3: The Northern firm's R&D investment increases the probability α that its marginal cost is low: $\alpha'(r) = \mathrm{d}\alpha(r)/\mathrm{d}r > 0$. However, the returns of the R&D investment are decreasing: $\alpha''(r) = \mathrm{d}^2\alpha(r)/\mathrm{d}r^2 \leq 0$.

The economic literature also considers decreasing returns for R&D expenditures (**Spencer and Brander, 1983**; **Reitzes, 1991**).[11] A good example of process R&D investment is the acquisition of cost-reducing production equipment. In this case, decreasing returns mean that the marginal effect of equipment decreases with the level of output. This assumption is important since it conditions a broad set of results, in particular how policy instruments affect R&D (positively or negatively). An implicit assumption is that the Southern firm learns the outcome of the Northern firm's R&D in a first stage. This is the simplest and most straightforward assumption. However, we may consider another situation in particular whether the domestic firm has an incentive to share information with its rival about R&D success or failure.

The Northern firm first sets the optimal level of R&D and, then, selects the optimal levels of domestic sales and exports. We begin by analyzing the second stage in which firms compete in production. Then, we study the first stage in which the Northern firm selects the optimal level of R&D that maximizes its expected profit.

[11] For example, **Spencer and Brander (1983)** consider cost-reducing R&D expenditures. They assume that the second derivative of total production costs with respect to R&D expenditures is negative.

1.2.1. Optimal Domestic Sales and Exports

In the second stage, each firm selects the optimal levels of domestic sales and exports that maximize their profit regardless of the level of the Northern firm's marginal cost. The profit expressions are:

$$\Pi(x_n, x_s, y_n, y_s) = x_n p_n(x_n + y_n) + x_s p_s(x_s + y_s) - c(x_n + x_s) - g x_s - F - vr \tag{1.2}$$

$$\Pi^*(x_n, x_s, y_n, y_s) = y_n p_n(x_n + y_n) + y_s p_s(x_s + y_s) - c^*(y_n + y_s) - g^* y_n - F^* \tag{1.3}$$

The first order conditions lead to the following reaction functions:

$$x_n(y_n) = \frac{c-p_n}{p_n'};\, x_s(y_s) = \frac{c+g-p_s}{p_s'};\, y_n(x_n) = \frac{c^*+g^*-p_n}{p_n'};\, y_s(x_s) = \frac{c^*-p_s}{p_s'}$$

Assumption 1.4: The second order conditions are verified on each market i: $\Pi_{x_i x_i} = x_i p_i'' + 2p_i' < 0; \Pi^*_{y_i y_i} = y_i p_i'' + 2p_i' < 0$. Cross effects are also negative: $\Pi_{x_i y_i} = x_i p_i'' + p_i' < 0; \Pi^*_{y_i x_i} = y_i p_i'' + p_i' < 0$. Own effects are greater than cross effects: $|\Pi_{x_i x_i}| > |\Pi_{x_i y_i}|; |\Pi^*_{y_i y_i}| > |\Pi^*_{y_i x_i}|$.[12]

The previous assumption implies that reaction functions are decreasing in the (x_i, y_i) space and that the Nash equilibrium's stability condition is verified on each market i. The slope of the Northern (Southern) firm's reaction function is greater in absolute value than that of the foreign firm on the Northern (Southern) market. We have: $D_i = \Pi_{x_i x_i}\Pi^*_{y_i y_i} - \Pi_{x_i y_i}\Pi^*_{y_i x_i} > 0$.

Let us demonstrate that the Northern firm is encouraged to invest in R&D by studying the impact of a change in c. Differentiating the first order conditions, we find: $\mathrm{d}x_i/\mathrm{d}c = \Pi^*_{y_i y_i}/D_i < 0; \mathrm{d}y_i/\mathrm{d}c = -\Pi^*_{y_i x_i}/D_i > 0; \mathrm{d}X_i/\mathrm{d}c = (\Pi^*_{y_i y_i} - \Pi^*_{y_i x_i})/D_i < 0$. The Northern (Southern) firm's domestic sales and exports decreases (increases) with the Northern firm's marginal cost. The total supply decreases with the Northern firm's marginal cost. As a consequence, each market price increases with c: $\mathrm{d}p_i/\mathrm{d}c = p_i'\,\mathrm{d}X_i/\mathrm{d}c > 0$. Finally, we study the impact on each profit. We denote by $\hat{x}_n$ ($\hat{y}_s$) the optimal level of the Northern (Southern) firm's domestic sales and $\hat{x}_s$ ($\hat{y}_n$) the optimal level of its exports. We also denote by $\hat{\Pi}$ ($\hat{\Pi}^*$) the Northern (Southern) firm's maximum profit such as it implements the optimal levels of domestic sales and exports: $\hat{\Pi} = \Pi(\hat{x}_n, \hat{x}_s); \hat{\Pi}^* = \Pi^*(\hat{y}_n, \hat{y}_s)$. We have:

$$\frac{\mathrm{d}\hat{\Pi}(c)}{\mathrm{d}c} = \frac{\partial\Pi(\hat{x}_n,\hat{x}_s)}{\partial c} + \frac{\partial\Pi(\hat{x}_n,\hat{x}_s)}{\partial\hat{x}_n}\frac{\mathrm{d}\hat{x}_n}{\mathrm{d}c} + \frac{\partial\Pi(\hat{x}_n,\hat{x}_s)}{\partial\hat{x}_s}\frac{\mathrm{d}\hat{x}_s}{\mathrm{d}c} = -\left(\frac{\hat{x}_n\Pi_{x_n x_n}\Pi^*_{y_n y_n}}{D_n} + \frac{\hat{x}_s\Pi_{x_s x_s}\Pi^*_{y_s y_s}}{D_s}\right) < 0 \tag{1.4}$$

$$\frac{\mathrm{d}\hat{\Pi}^*(c)}{\mathrm{d}c} = \frac{\partial\Pi^*(\hat{y}_n,\hat{y}_s)}{\partial c} + \frac{\partial\Pi(\hat{y}_n,\hat{y}_s)}{\partial\hat{y}_n}\frac{\mathrm{d}\hat{y}_n}{\mathrm{d}c} + \frac{\partial\Pi(\hat{y}_n,\hat{y}_s)}{\partial\hat{y}_s}\frac{\mathrm{d}\hat{y}_s}{\mathrm{d}c} = \frac{\hat{y}_n\Pi^*_{y_n y_n}\Pi^*_{y_n x_n}}{D_n} + \frac{\hat{y}_s\Pi^*_{y_s y_s}\Pi^*_{y_s x_s}}{D_s} > 0 \tag{1.5}$$

The Northern (Southern) firm's profit decreases (increases) with the Northern firm's marginal cost. Therefore, the Northern firm is encouraged to invest in R&D in order to benefit from a low marginal cost and to increase its profit.

[12] Subscripts denote partial derivatives.

1.2.2. A Linear Example

In the body of this chapter, we use specific inverse demand functions in order to have a clear outcome. Consider linear inverse demand functions: $p_i(X_i) = a_i - X_i$, where a_i denotes the fixed part of the inverse demand function. Each firm selects the optimal levels of domestic sales and exports that maximize their profit, denoted by $\hat{x}_n$, $\hat{x}_s$, $\hat{y}_n$ and $\hat{y}_s$.[13] We have:

$$\hat{x}_n = \frac{a_n-2c+c^*+g^*}{3}; \hat{x}_s = \frac{a_s-2c+c^*-2g}{3}; \hat{y}_n = \frac{a_n+c-2c^*-2g^*}{3}; \hat{y}_s = \frac{a_s+c-2c^*+g}{3} \quad (1.6)$$

The equilibrium market prices denoted by $\hat{p}_n$ and $\hat{p}_s$ are:

$$\hat{p}_n = \frac{a_n+c+c^*+g^*}{3}; \hat{p}_s = \frac{a_s+c+c^*+g}{3} \quad (1.7)$$

Finally, the equilibrium profits $\hat{\Pi}$ and $\hat{\Pi}^*$ are:

$$\hat{\Pi} = \frac{(a_n-2c+c^*+g^*)^2}{9} + \frac{(a_s-2c+c^*-2g)^2}{9} - F - vr; \hat{\Pi}^* = \frac{(a_n+c-2c^*-2g^*)^2}{9} + \frac{(a_s+c-2c^*+g)^2}{9} - F^* \quad (1.8)$$

According to these expressions, the marginal cost c reduces (increases) the Northern (Southern) firm's domestic sales, exports and profit. It also increases each market price.

1.2.3. Optimal R&D Investment

The R&D outcome is uncertain. The Northern firm's marginal cost may be either low or high. In the first stage, the Northern firm selects the optimal level of R&D that maximizes its expected profit by anticipating the previous results. We denote by $\pi^j; \forall j = \{l, h\}$ the Northern firm's profit that depends on the value of its marginal cost $c^j; \forall j = \{l, h\}$, R&D and fixed costs excluded.[14] We have: $\hat{\pi}^j = \hat{x}_n^j \hat{p}_n^j + \hat{x}_s^j \hat{p}_s^j - c^j(\hat{x}_n^j + \hat{x}_s^j)$. Let us call $E[.]$ the expectation operator with respect to the R&D outcome. We have:

$$E[\Pi(r)] = \alpha(r)\hat{\pi}^l + [1-\alpha(r)]\hat{\pi}^h - F - vr \quad (1.9)$$

The first order condition gives:

$$\alpha'(r) = \frac{v}{\hat{\pi}^l - \hat{\pi}^h} \quad (1.10)$$

Using the specific linear inverse demand functions, the difference in profit equals:

$$\hat{\pi}^l - \hat{\pi}^h = \frac{4(c^h-c^l)(a_n+a_s-2c_h-2g+g^*)}{9}$$

Then, we have:

$$\alpha'(r) = \frac{9v}{4(c^h-c^l)(a_n+a_s-2c_h-2g+g^*)}$$

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[13] In each chapter, the hat operator denotes the equilibrium expression for the variable.

[14] Each endogenous variable depends on the Northern firm's marginal cost c^j. Therefore, we use the superscript j. For example, $\hat{x}_n^j$ denotes the Northern firm's equilibrium domestic sales when its marginal cost is $c^j; \forall j = \{l, h\}$.

A simple interpretation of the previous equation stems for rewriting the Northern firm's R&D investment as a function of the difference in profit $\left(\hat{\pi}^l - \hat{\pi}^h\right)$ and of the unit R&D cost v: $r = \psi\left[v, \left(\hat{\pi}^l - \hat{\pi}^h\right)\right]$, with $\partial\psi/\partial\left(\hat{\pi}^l - \hat{\pi}^h\right) > 0$ and $\partial\psi/\partial v < 0$. Therefore, we can study the impact of any policy instrument on the R&D investment by analyzing the impact on the difference in profit and on the total cost of R&D.

1.3. Policy Instruments Implemented by the Northern Government

We study the impact of several policy instruments implemented by the government of the Northern country on domestic R&D: an import tariff, a production subsidy, an R&D subsidy, an import quota, a VER and a minimum price. The implementation of policy instruments aim to increase both the probability of successful R&D and the national welfare. We make a welfare analysis in Section 1.5 to ascertain whether or not governments are encouraged to implement such policy instruments. Figure 1.1 illustrates the timing of the model.

-Figure 1.1-

Structure of the Model under Cournot Competition

Source: author.

First, the Northern government selects the optimal level of the policy instruments that maximizes the Northern country's national welfare by anticipating the levels of R&D, domestic sales and exports. We have:

$$E(\mathrm{W}) = E(\Pi) + E(\mathrm{CS}) + E(\mathrm{PR}) \tag{1.11}$$

The term W denotes the Northern country's national welfare; CS the Northern country's consumer surplus; and PR the Northern country's public revenues.

Second, the Northern firm selects the optimal level of R&D that maximizes its expected profit by anticipating each level of exports and domestic sales. Third, each firm selects the optimal levels of domestic sales and exports that maximize their profit. Note that we solve the model by starting with the third stage for each instrument. Then, we find the optimal level of R&D. We finish by finding the optimal level of the public policy instrument because we need to know the equilibrium expression for each variable.

1.3.1. An Import Tariff

The Northern government implements an import tariff. We denote by t the Northern government's specific import tariff. The Southern firm's profit expression, fixed and R&D costs excluded, is modified into:

$$\pi^{*j} = y_n^j p_n^j\left(x_n^j + y_n^j\right) + y_s^j p_s^j\left(x_s^j + y_s^j\right) - c^l\left(y_n^j + y_s^j\right) - (g^* + t)y_n^j; \forall j = \{l,h\} \tag{1.12}$$

In the second stage, the economic impact of the import tariff is the same as that of an increase in the Southern firm's unit transport cost. According to previous equilibrium expressions, we can find the impact of the import tariff. The Northern (Southern) firm's domestic sales (exports) increase (decrease) with the import tariff as compared to free trade. The total supply decreases on the Northern market. The Northern market price increases. There is a direct negative impact on the Northern country's consumer surplus. Note that the import tariff has only an impact on the Northern market. Therefore, it does not directly influence the Northern firm's exports, the Southern firm's domestic sales and the Southern market price. Finally, the Northern (Southern) firm's profit increases (decreases) with the tariff.

In the first stage, the Northern firm selects the optimal level of R&D expenditures that maximizes its expected profit. The first order condition involves the same expression as under free trade, but the difference in profit now depends on the import tariff: $\hat{\pi}^l(t) - \hat{\pi}^h(t)$.

Proposition 1.1: With the specific inverse demand functions, the Northern firm's R&D investment increases with the implementation of the Northern government's import tariff as compared to free trade.

Proof: □ We have:

$$\hat{\pi}^j(t) = \frac{\left(a_n - 2c^j + c^l + g^* + t\right)^2 + \left(a_s - 2c^j + c^l - 2g\right)^2}{9}$$

Hence, the difference in profit equals:

$$\hat{\pi}^l(t) - \hat{\pi}^h(t) = \frac{4\left(c^h - c^l\right)\left(a_n + a_s - 2c_h - 2g + g^* + t\right)}{9}$$

Therefore, the difference in profit increases with the tariff:

$$\frac{\mathrm{d}\left[\hat{\pi}^l(t) - \hat{\pi}^h(t)\right]}{\mathrm{d}t} = \frac{4\left(c^h - c^l\right)}{9} > 0$$

The Northern firm's R&D investment increases with the Northern government's import tariff. □

Let us explain such a result. The import tariff reduces the Southern firm's exports. The Northern firm's profit increases when the Southern firm's exports decrease. The direct impact of such a drop on the Northern firm's profit equals its domestic sales: $\partial\pi^j/\partial y_n^j = -x_n^j < 0$. Furthermore, the Northern firm's domestic sales are greater when its marginal cost is low which means that the positive impact of the drop in the Southern firm's exports on the Northern firm's profit is greater when the marginal cost is low. As a consequence, the difference in profit and the R&D investment increases with the import tariff.

However, we cannot find this result by using general forms for inverse demand functions. The effect of the tariff on the R&D is always positive with any other linear form. But under nonlinear forms, we cannot demonstrate that the effect is always positive (see Appendix 1.A).

The positive impact of the import tariff relates to the results illustrated in the economic literature (**Krugman, 1984**; **Reitzes, 1991**; **Bouët, 2001**). The tariff involves a profit-shifting from the South to the North. Such a profit-shifting is greater when the R&D is successful. The Northern firm is encouraged to innovate. Governments may improve their domestic price-competitiveness by implementing trade policy instruments like tariffs.

1.3.2. A Production Subsidy

Consider that the Northern government subsidizes the domestic firm's production i.e. both domestic sales and exports. We denote by s the specific production subsidy. The domestic firm's profit is modified into:

$$\pi^j = x_n^j p_n^j\left(x_n^j + y_n^j\right) + x_s^j p_s^j\left(x_s^j + y_s^j\right) - \left(c^j - s\right)\left(x_n^j + x_s^j\right) - g x_s^j; \forall j = \{l, h\} \tag{1.13}$$

The economic impact of the production subsidy is the same as that of a drop in the Northern firm's marginal cost. According to the impact of c, we can find the effect of s on domestic sales, exports, prices and profits. The Northern (Southern) firm's domestic sales and exports increase (decrease) with the production subsidy. The effect on the total supply is positive on each market. The production subsidy reduces each market price. Therefore, there is a direct positive impact on each country's consumer surplus. The production subsidy also increases (reduces) the Northern (Southern) firm's profit. Finally, it involves further public expenditures for the Northern government. The effect on public revenues is negative.

Now, let us study the impact of the production subsidy on the Northern firm's R&D investment via the effect on the difference in profit.

Proposition 1.2: With the specific inverse demand functions, the Northern firm's R&D investment increases with the implementation of the Northern government's production subsidy as compared to free trade.

Proof: □ We have:

$$\hat{\pi}^j(s) = \frac{\left(a_n - 2c^j + c^l + g^* + 2s\right)^2 + \left(a_s - 2c^j + c^l - 2g + 2s\right)^2}{9}$$

Hence, the difference in profit equals:

$$\hat{\pi}^l(s) - \hat{\pi}^h(s) = \frac{4\left(c^h - c^l\right)\left(a_n + a_s - 2c^h - 2g + g^* + 4s\right)}{9}$$

Therefore, the difference in profit increases with the production subsidy:

$$\frac{\mathrm{d}[\hat{\pi}^l(s)-\hat{\pi}^h(s)]}{\mathrm{d}s} = \frac{16(c^h-c^l)}{9} > 0$$

The Northern firm's R&D investment increases with the Northern government's production subsidy. □

Let us explain such a result. The direct positive impact of the production subsidy on the Northern firm's profit equals its output: $\partial\pi^j/\partial s = x_n^j + x_s^j > 0$. Furthermore, the Northern firm's domestic sales and exports are greater when its marginal cost is low. The difference in profit and the R&D investment are stronger with the production subsidy as compared to free trade.

Note that the effect seems to be stronger than the impact of an import tariff. The reason is that the production subsidy has a direct positive impact on the Northern firm's profit while the tariff has only an indirect positive impact by reducing competition from the South.

However, we cannot demonstrate such a result with general forms for inverse demand functions. The effect is positive for any other linear form, but uncertain for nonlinear functions (see Appendix 1.A).

1.3.3. An R&D Subsidy

The Northern government may also subsidize R&D expenditures. We denote by σ the R&D subsidy. The Northern firm's profit is:

$$\pi^j = x_n^j p_n^j(x_n^j + y_n^j) + x_s^j p_s^j(x_s^j + y_s^j) - c^j(x_n^j + x_s^j) - F - (v-\sigma)r; \forall j = \{l,h\} \tag{1.14}$$

The first and second order conditions do not change compared to the initial situation without R&D subsidy. Furthermore, we have: $\pi_{x_i\sigma}^j = 0$; which leads to: $\mathrm{d}x_i^j/\mathrm{d}\sigma = 0$. Therefore, the R&D subsidy does not directly modify domestic sales, exports, price and profits.

In the first stage, the R&D subsidy influences the R&D investment. The first order condition gives:

$$\alpha'(r) = \frac{v-\sigma}{\hat{\pi}^l - \hat{\pi}^h} \tag{1.15}$$

Proposition 1.3: The Northern firm's R&D investment increases with the implementation of the Northern government's R&D subsidy.

Proof: □ The R&D subsidy reduces the numerator of the previous equation. Therefore, it increases the R&D investment since $\alpha''(r) \leq 0$. The reason is that the R&D subsidy reduces the domestic firm's R&D cost which now equals: $(v-\sigma)r$. Such a result holds under general forms for the inverse demand function. □

1.3.4. A Public R&D Investment

It can be argued that the previous policy instrument is unrealistic. The distinction between R&D in volume (r) and price (v) may be difficult to identify in reality. Consequently, a public intervention aimed at directly increasing R&D would take another form. Consider now that the Northern government's intervention consists in an additional public R&D investment in volume denoted by $\overline{r}$.

Proposition 1.4: The Northern firm's private R&D investment decreases with the Northern government's public R&D investment. The total (public and private) R&D is unchanged as compared to the initial situation without public R&D.

Proof: □ Such an additional public R&D investment $\overline{r}$ does not influence the Northern firm's profit. However, it changes the first order condition by selecting its optimal level of R&D. It becomes: $\alpha'(r+\overline{r}) = v/(\hat{\pi}^l - \hat{\pi}^h)$. Since the right side of the previous equation is unchanged and $\alpha'' \leq 0$, the public R&D investment reduces the Northern firm's private R&D investment by the same amount. The total (public and private) R&D is unchanged. It is a pure transfer from the Northern government to the Northern firm. □

1.3.5. An Import Quota

Consider that the Northern government implements an import quota. We assume that the quota does not create public revenues because imports licenses are free. An introduction of quota revenues under imperfect competition is a really a complex issue. For **Matschke (2003)**, in a duopolistic context under Cournot competition, *"modeling the quota revenue is somewhat arbitrary* [p. 212]." Many academic articles proceed along the same assumption. See for example **Bouët and Cassagnard (2013)**.

Let us suppose that the quota is binding and that q denotes the quota level (i.e. the Southern firm's maximum exports). If the Southern firm's exports equal q, the profit expressions are now:

$$\pi^j = x_n^j p_n^j(x_n^j + q) + x_s^j p_s^j(x_s^j + y_s^j) - c^j(x_n^j + x_s^j) - g x_s^j; \forall j = \{l, h\} \tag{1.16}$$

$$\pi^{*j} = q p_n^j(x_n^j + q) + y_s^j p_s^j(x_s^j + y_s^j) - c^l(y_n^j + y_s^j) - g^* q; \forall j = \{l, h\} \tag{1.17}$$

In the second stage, the Southern firm cannot select the optimal level of exports that maximizes its profit. The Northern firm's domestic sales and the total supply on the Northern market equal:

$$\hat{x}_n^j(q) = \frac{a_n - c^j - q}{2}; \hat{X}_n^j(q) = \frac{a_n - c^j + q}{2}; \forall j = \{l, h\} \tag{1.18}$$

A binding quota increases the Northern firm's domestic sales. The Northern firm is encouraged to increase its domestic sales because competition from the South decreases. The total supply decreases as compared to free trade because the quota is binding.

The Northern market price equals:

$$\hat{p}_n^j(q) = \frac{a_n + c^j - q}{2}; \forall j = \{l, h\} \tag{1.19}$$

The Northern market price increases as compared to free trade because the Southern firm's exports are lower.

Note that the quota has no direct impact on the Southern market. There is only an indirect effect by changing the level of R&D. The Northern (Southern) firm's domestic sales (exports), the total supply on the Southern market and the Southern market price equal free trade levels.

The equilibrium profits are:

$$\hat{\pi}^j(q) = \frac{(a_n - c^j - q)^2}{4} + \frac{(a_s - 2c^j + c^l - 2g^*)^2}{9}; \hat{\pi}^{*j}(q) = \frac{q(a_n + c^j - 2c^l - 2g^* - q)}{4} + \frac{(a_s + c^j - 2c^l - 2g^*)^2}{9}; \forall j = \{l, h\} \tag{1.20}$$

The Northern firm's profit increases as compared to free trade owing to the drop in competition from the Southern country. The Southern firm's profit decreases because the level of exports is no longer optimal.

We consider two cases for the quota level. The first case corresponds to a relatively binding quota while the second corresponds to a strongly binding quota.

- First case: $\hat{y}_n^l \leq q < \hat{y}_n^h$. The quota is relatively binding. If the Northern firm's marginal cost is low, the quota is greater than the Southern firm's optimal exports. In this case, the Northern profit does not change. But, if such a marginal cost is high, the quota is binding and the Southern firm has to export less than the free trade equilibrium level. The quota only increases the Northern firm's profit under an unsuccessful R&D. The effect is null under a successful R&D. Denoting as $\hat{\pi}^j(q)$ the Northern firm's profit with the quota and $\hat{\pi}^j$ its free trade profit with $j = \{l, h\}$, we have: $\hat{\pi}^l(q) = \hat{\pi}^l; \hat{\pi}^h(q) > \hat{\pi}^h$.
- Second case: $q < \hat{y}_n^l$. The quota is strongly binding. Under both cases, the quota is lower than the Southern firm's free trade exports. In this case, the Northern firm's profit increases regardless of the R&D outcome. We have: $\hat{\pi}^l(q) > \hat{\pi}^l; \hat{\pi}^h(q) > \hat{\pi}^h$.

We omit the case in which the quota is not binding at all i.e. $q \geq \hat{y}_n^h$. In this case, the Northern firm's profit remains the same as under free trade regardless of the R&D outcome.

The Northern firm selects the optimal level of R&D investment. We have:

$$\alpha'(r) = \frac{v}{\hat{\pi}^l(q) - \hat{\pi}^h(q)} \tag{1.21}$$

Proposition 1.5: The Northern firm's R&D investment always decreases as compared to free trade with a relatively binding quota (first case). With a strongly binding quota, there is a non-null level of quota $\overline{q}$ such as the R&D investment equals the free trade level. Therefore, the Northern firm's R&D investment decreases as compared to free trade if $q \in (\overline{q}, \hat{y}_n^l)$, levels off if $q = \overline{q}$, and increases if $q \in [0, \overline{q})$. With a prohibitive quota, the R&D investment always increases.

Proof: □ Let us study the two cases:

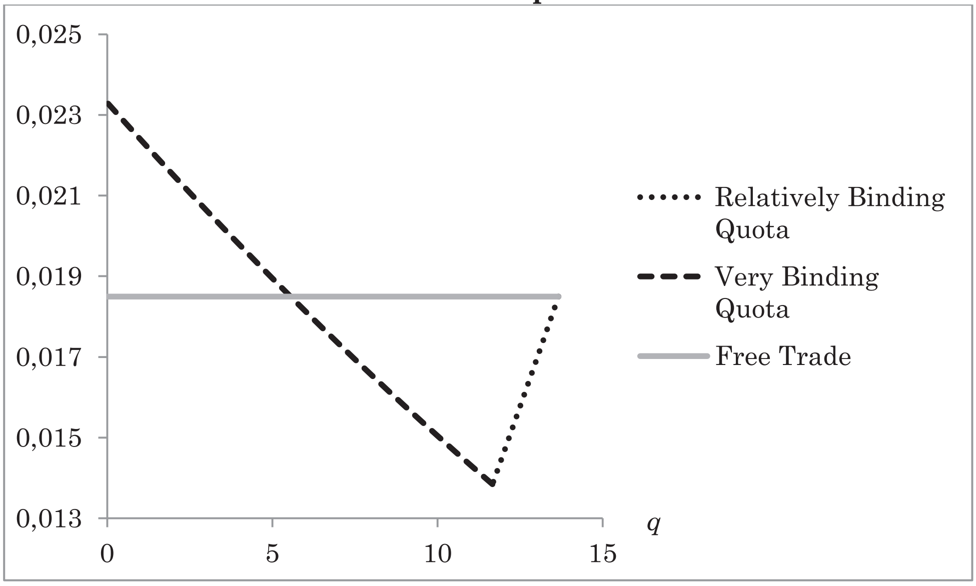
- With a relatively binding quota (first case), the Northern firm's profit increases only when the R&D is unsuccessful. The difference in profit decreases with the quota as compared to free trade. Therefore, the R&D investment also decreases.
- With a strongly binding quota (second case), the Northern firm's profit increases whatever the R&D outcome. The difference in profit equals:
  $\pi^l(q) - \pi^h(q) = \frac{(c^h - c^l)(2a_n - c^l - c^h - 2q)}{4} + \frac{4(c^h - c^l)(a_s - c^h - 2g)}{9}$
  Then, we have:
  $\frac{\mathrm{d}[\pi^l(q) - \pi^h(q)]}{\mathrm{d}q} = -\frac{c^h - c^l}{2} < 0$
  The difference in profit increases when the quota q decreases. But, since a relatively binding quota reduces the R&D, such a result is not sufficient to prove that the difference in profit always increases as compared to free trade. There is a non-null level of quota, denoted by $\overline{q}$, such as the previous expression equals the free trade level:
  $\overline{q} = \frac{2a_n - 9c^l + 7c^h - 16g^*}{18} > 0$
  The value of such a quota $\overline{q}$ is lower than $\hat{y}_n^l$:
  $\overline{q} - \hat{y}_n^l = -\frac{(4a_n + 3c^l - 7c^h + 4g^*)}{18} < 0$
  Therefore, the difference in profit decreases with a strongly binding quota as compared to free trade if $q \in (\overline{q}, \hat{y}_n^l)$. The difference in profit increases with a strongly binding quota, otherwise. For example, it increases with a prohibitive quota.

A relatively binding quota always reduces the Northern firm's R&D investment. The firm is encouraged to reduce its investment because the competition only decreases when the R&D is unsuccessful. A strongly binding quota either increases or reduces the Northern firm's R&D investment as compared to free trade because there is a threshold $\overline{q}$ such as the Northern firm's R&D increases with a lower level for q.

Let us use a numerical example: $a_n = 40; a_s = 30; c^h = 9; c^l = 3; g = g^* = 1; k = 0.5, v = 500$. Under free trade, we have: $\hat{y}_n^l = 11.6667; \hat{y}_n^l = 13.6667$. Figure 1.2 illustrates the evolution of the R&D investment when the level of the quota varies. The grey line illustrates the free trade level. Here, we find $\overline{q} \approx 5.5556$, with $0 < \overline{q} < \hat{y}_n^l$. Under such a numerical example, the R&D investment decreases with a strongly binding quota as compared to free trade if $q \in (\overline{q}, \hat{y}_n^l)$. It levels off if $q = \overline{q}$. It increases if $q \in [0, \overline{q})$. □

-Figure 1.2-

Evolution of the Northern Firm's R&D Investment When *q* Varies under Cournot Competition



Source: author.
Note: $\alpha(r) = r^k; a_n = 40; a_s = 30; c^h = 9; c^l = 3; g = g^* = 1; k = 0.5, v = 500$.

Comparing the impact of an import quota and that of an import tariff is interesting. The effect of the first (second) on the R&D investment is either positive or negative (always positive). However, both instruments reduce competition from the Southern country.

The negative impact of import quotas on R&D investments has already been illustrated in the theoretical economic literature (**Reitzes, 1991**; **Bouët, 2001**). Authors also find a positive (negative) impact of an import tariff (quota) implemented by the domestic government. The economic literature explains the difference between these instruments by mentioning that quotas change the strategic relationship among firms while tariffs do not (**Bhagwati, 1968**; **Krishna, 1989**).

With a quota, the Northern firm benefits from an advantage in terms of information. Since the quota is binding, it already knows the level of its competitor's exports before selecting its domestic sales. The Southern firm no longer sets the optimal level of exports. On the Northern market, the Northern firm selects the optimal level of domestic sales without considering the Southern firm's first order condition.

1.3.6. A Voluntary Exports Restraint (VER)

Quantitative restrictions can also take the form of Voluntary Exports Restraints (VER). Because such a policy is "voluntary," it must be implemented by the Southern country. According to **Bouët (2001)**, in the same theoretical structure, a VER has a strategic interest. The Southern government implements a VER denoted by q_v such as: $\hat{y}_n^l \leq q_v < \hat{y}_n^h$. Therefore, the Northern firm's R&D decreases as compared to free trade because its profit only increases if its marginal cost is high. It decreases the marginal gain of an R&D investment. **Bouët (2001)** shows that a VER can increase the Southern firm's expected profit because the probability of R&D success is lower. Therefore, a VER must be such as $\hat{y}_n^l \leq q_v < \hat{y}_n^h$. The Southern firm's profit is always lower regardless of the impact on the R&D investment, otherwise.

Proposition 1.6: The Northern firm's R&D investment decreases with the Southern government's VER.

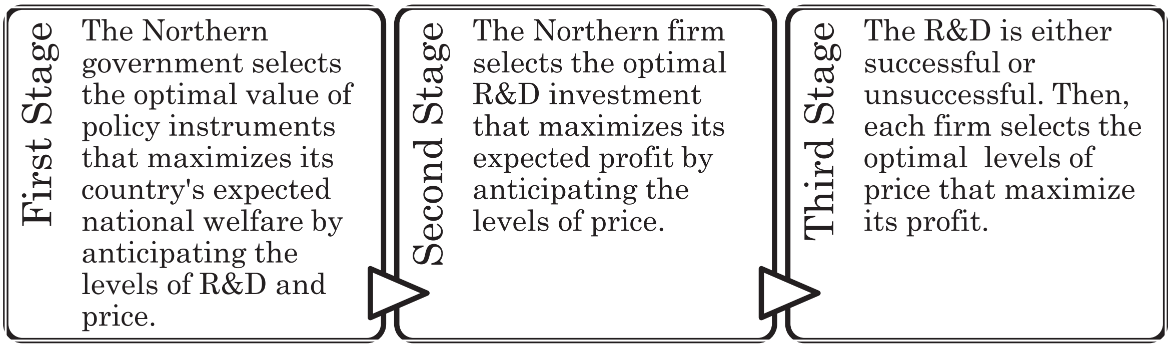
1.4. Bertrand Competition

Let us introduce now price competition. **Maggi (1996)** proved that *"the optimal trade policy depends on the mode of competition* [p. 251]." Therefore, we verify whether or not our previous results hold under Bertrand competition.

Figure 1.3 illustrates the structure of the model under price competition.

-Figure 1.3-

Structure of the Model under Bertrand Competition



Source: authors.

We denote by p_n (p_s) the Northern firm's price on the Northern (Southern) market and p_n^* (p_s^*) the Southern firm's price on the Northern (Southern) market. To avoid a "Bertrand Paradox," we assume that goods are slightly differentiated.

Assumption 1.5: Both firms produce slightly differentiated goods. There is Bertrand competition on each market. Domestic sales and exports depend on both domestic and foreign prices: $x_i = x_i(p_i, p_i^*); y_i = y_i(p_i, p_i^*)$. Each firm's domestic sales and exports decreases (increases) with the domestic (foreign) price: $\partial x_i/\partial p_i < 0; \partial x_i/\partial p_i^* > 0; \partial y_i/\partial p_i > 0; \partial y_i/\partial p_i^* < 0$. We have: $|\partial x_i/\partial p_i| > \partial x_i/\partial p_i^*\,; \partial y_i/\partial p_i < |\partial y_i/\partial p_i^*|$.

In the second stage, each firm selects the optimal levels of price that maximize its profit. Each level of price, domestic sales, exports and profit depends on the R&D outcome. Therefore, we use the superscript j again. The profit expressions are:

$$\pi^j(p_n^j, p_s^j, p_n^{*j}, p_s^{*j}) = p_n^j x_n^j(p_n^j, p_n^{*j}) + p_s^j x_s^j(p_s^j, p_s^{*j}) - c^j[x_n^j(p_n^j, p_n^{*j}) + x_s^j(p_s^j, p_s^{*j})] - g x_s^j(p_s^j, p_s^{*j}); \forall j = \{l, h\} \tag{1.22}$$

$$\pi^{*j}(p_n^j, p_s^j, p_n^{*j}, p_s^{*j}) = p_n^{*j} y_n^j(p_n^j, p_n^{*j}) + p_s^{*j} y_s^j(p_s^j, p_s^{*j}) - c^l[y_n^j(p_n^j, p_n^{*j}) + y_s^j(p_s^j, p_s^{*j})] - g^* y_n^j(p_s^j, p_s^{*j}); \forall j = \{l, h\} \tag{1.23}$$

The first order condition leads to: $p_i^j(p_i^{*j}) = c^j - x_i^j/x_{i\,p_i}^j\,; p_i^{*j}(p_i^j) = c^l - y_i^j/y_{i\,p_i^*}^j$.

Assumption 1.6: The second order conditions are verified: $\pi^j_{p_ip_i} = x^j_{i\ p_ip_i}(p^j_i - c^j) + 2x^j_{i\ p_i} < 0; \pi^{*j}_{p^*_ip^*_i} = y^j_{i\ p^*_ip^*_i}(p^{*j}_i - c^l) + 2y^j_{i\ p^*_i} < 0$. Cross effects are positive: $\pi^j_{p_ip^*_i} = x^j_{i\ p_ip^*_i}(p^j_i - c^j) + 2x^j_{i\ p^*_i} > 0; \pi^{*j}_{p^*_ip_i} = y^j_{i\ p^*_ip_i}(p^{*j}_i - c^l) + 2y^j_{i\ p_i} > 0$. Nevertheless, own effects are greater than cross effects: $|\pi^j_{p_ip_i}| > \pi^j_{p_ip^*_i}; |\pi^{*j}_{p^*_ip^*_i}| > \pi^{*j}_{p^*_ip_i}$.

Such an assumption involves the Nash equilibrium's stability condition on each market: $E^j_i = \pi^j_{p_ip_i}\pi^{*j}_{p^*_ip^*_i} - \pi^j_{p_ip^*_i}\pi^{*j}_{p^*_ip_i} > 0$.

1.4.1. A Linear Example

Consider the following linear demand functions on each market: $x^j_i = a_i - b_ip^j_i + p^{*j}_i; y^j_i = a_i + p^j_i - b_ip^{*j}_i$, where a_i denotes the fixed part of demand functions and b_i the horizontal differentiation with $b_i > 1; \forall i = \{n, s\}$. Each firm selects the optimal levels of price:

$$\hat{p}^j_n = \frac{a_n(2b_n+1)+2b_n^2c^j+b_n(c^l+g^*)}{4b_n^2-1}; \hat{p}^j_s = \frac{a_s(2b_s+1)+2b_s^2(c^j+g)+b_sc^l}{4b_s^2-1};$$

$$\hat{p}^{*j}_n = \frac{a_n(2b_n+1)+b_nc^j+2b_n^2(c^l+g^*)}{4b_n^2-1}; \hat{p}^{*j}_s = \frac{a_s(2b_s+1)+b_s(c^j+g)+2b_s^2c^l}{4b_s^2-1}; \forall j = \{l, h\} \quad (1.24)$$

Each level of price increases with the Northern firm's marginal cost and is lower when $c^j = c^l$.

The levels of domestic sales and exports are:

$$\hat{x}^j_n = \frac{b_n[a_n(2b_n+1)-(2b_n^2-1)c^j+b_n(c^l+g^*)]}{4b_n^2-1}; \hat{x}^j_s = \frac{b_s[a_s(2b_s+1)-(2b_s^2-1)(c^j+g)+b_sc^l]}{4b_s^2-1};$$

$$\hat{y}^j_n = \frac{b_n[a_n(2b_n+1)+b_nc^j-(2b_n^2-1)(c^l+g^*)]}{4b_n^2-1}; \hat{y}^j_s = \frac{b_s[a_s(2b_s+1)+b_s(c^j+g)-(2b_s^2-1)c^l]}{4b_s^2-1}; \forall j = \{l, h\} \quad (1.25)$$

The Northern (Southern) firm's domestic sales and exports decrease (increase) with the marginal cost c^j. The Northern (Southern) firm's market shares are greater (lower) when the Northern marginal cost is low.

The expressions of equilibrium profit are:

$$\hat{\pi}^j = \frac{b_n[a_n(2b_n+1)-(2b_n^2-1)c^j+b_n(c^l+g^*)]^2}{(4b_n^2-1)^2} + \frac{b_s[a_s(2b_s+1)-(2b_s^2-1)(c^j+g)+b_sc^l]^2}{(4b_s^2-1)^2};$$

$$\hat{\pi}^{*j} = \frac{b_n[a_n(2b_n+1)+b_nc^j-(2b_n^2-1)(c^l+g^*)]^2}{(4b_n^2-1)^2} + \frac{b_s[a_s(2b_s+1)+b_s(c^j+g)-(2b_s^2-1)c^l]^2}{(4b_s^2-1)^2}; \forall j = \{l, h\} \quad (1.26)$$

The Northern (Southern) firm's profit increases (decreases) with the Northern firm's marginal cost. The Northern (Southern) firm's profit is higher (lower) when $c^j = c^l$.

The Northern firm's difference in profit equals:

$$\hat{\pi}^l - \hat{\pi}^h = \frac{b_n(2b_n^2-1)(c^h-c^l)[2a_n(2b_n+1)-(2b_n^2-1)(c^l+c^h)+2b_n(c^l+g^*)]}{(4b_n^2-1)^2} + \frac{b_s(2b_s^2-1)(c^h-c^l)[2a_s(2b_s+1)-(2b_s^2-1)(c^l+c^h+2g)+2b_sc^l]}{(4b_s^2-1)^2}$$

(1.27)

We study the impact of each policy instrument under Bertrand competition in order to verify whether or not the results hold. Nevertheless, we do not study the impact of the R&D subsidy because it does not influence the profit, R&D and fixed costs excluded. We also study the impact of a minimum price.

1.4.2. An Import Tariff

Consider a specific import tariff implemented by the Northern government. The Southern firm's profit expression is now:

$$\pi^{*j} = p_n^{*j} y_n^j\left(p_n^j, p_n^{*j}\right) + p_s^{*j} y_s^j\left(p_s^j, p_s^{*j}\right) - c^l\left[y_n^j\left(p_n^j, p_n^{*j}\right) + y_s^j\left(p_s^j, p_s^{*j}\right)\right] - (g^* + t) y_n^j\left(p_s^j, p_s^{*j}\right); \forall j = \{l, h\} \tag{1.28}$$

According to the impact of g^*, the tariff increases each level of price on the Northern market. It increases (reduces) the Northern (Southern) firm's domestic sales (exports) and profit. The total level of supply decreases on the Northern market. Therefore, there is a positive direct impact on the Northern country's consumer surplus.

Proposition 1.7: Under Bertrand competition, the Northern firm's R&D investment increases with the implementation of the Northern government's import tariff as compared to free trade.

Proof: □ We have:

$$\hat{\pi}^j(t) = \frac{b_n\left[a_n(2b_n+1) - (2b_n^2-1)c^j + b_n(c^l+g^*+t)\right]^2}{\left(4b_n^2-1\right)^2} + \frac{b_s\left[a_s(2b_s+1) - (2b_s^2-1)(c^j+g) + b_s c^l\right]^2}{\left(4b_s^2-1\right)^2}$$

The difference in profit equals:

$$\hat{\pi}^l(t) - \hat{\pi}^h(t) = \frac{b_n(2b_n^2-1)(c^h-c^l)\left[2a_n(2b_n+1) - (2b_n^2-1)(c^l+c^h) + 2b_n(c^l+g^*+t)\right]}{\left(4b_n^2-1\right)^2} + \frac{b_s(2b_s^2-1)(c^h-c^l)\left[2a_s(2b_s+1) - (2b_s^2-1)(c^l+c^h+2g) + 2b_s c^l\right]}{\left(4b_s^2-1\right)^2}$$

The difference in profit increases with the tariff:

$$\frac{\mathrm{d}\left[\hat{\pi}^l(t) - \hat{\pi}^h(t)\right]}{\mathrm{d}t} = \frac{2b_n^2(2b_n^2-1)(c^h-c^l)}{\left(4b_n^2-1\right)^2} > 0$$

Therefore, the Northern firm increases its R&D investment. □

The tariff reduces competition from the South and increases in the Southern firm's price on the Northern market. The effect of the increase in the Southern firm's price of exports on the Northern firm's profit equals: $\partial\pi^j / \partial p_n^{*j} = \left(p_n^j - c^j\right) > 0$. Such a positive impact is greater when $c^j = c^l$. This is the reason why the Northern firm is encouraged to increase its R&D investment.

As under Cournot competition, we cannot make general conclusions. The result holds under any other linear form for demand functions. But, we cannot demonstrate that they hold under nonlinear forms (see Appendix 1.B).

1.4.3. A Production Subsidy

Consider a production subsidy implemented by the Northern government. The Northern firm's profit expression now equals:

$$\pi^j = p_n^j x_n^j(p_n^j, p_n^{*j}) + p_s^j x_s^j(p_s^j, p_s^{*j}) - (c^j - s)[x_n^j(p_n^j, p_n^{*j}) + x_s^j(p_s^j, p_s^{*j})] - g x_s^j(p_s^j, p_s^{*j}); \forall j = \{l, h\} \quad (1.29)$$

According to the impact of the Northern firm's marginal cost, the production subsidy reduces each level of price. It increases (reduces) the Northern (Southern) firm's domestic sales, exports and profit. The effect on the total supply is positive on each market.

Proposition 1.8: Under Bertrand competition, the Northern firm's R&D investment increases with the implementation of the Northern government's production subsidy.

Proof: □ We have:

$$\hat{\pi}^j(s) = \frac{b_n[a_n(2b_n+1)-(2b_n^2-1)(c^j-s)+b_n(c^l+g^*)]^2}{(4b_n^2-1)^2} + \frac{b_s[a_s(2b_s+1)-(2b_s^2-1)(c^j+g-s)+b_s c^l]^2}{(4b_s^2-1)^2}$$

The difference in profit equals:

$$\hat{\pi}^l(s) - \hat{\pi}^h(s) = \frac{b_n(2b_n^2-1)(c^h-c^l)[2a_n(2b_n+1)-(2b_n^2-1)(c^l+c^h-2s)+2b_n(c^l+g^*)]}{(4b_n^2-1)^2} + \frac{b_s(2b_s^2-1)(c^h-c^l)[2a_s(2b_s+1)-(2b_s^2-1)(c^l+c^h+2g-2s)+2b_s c^l]}{(4b_s^2-1)^2}$$

The difference in profit increases with the tariff:

$$\frac{\mathrm{d}[\hat{\pi}^l(s)-\hat{\pi}^h(s)]}{\mathrm{d}s} = 2(c^h - c^l)\left[\frac{b_n(2b_n^2-1)^2}{(4b_n^2-1)^2} + \frac{b_s(2b_s^2-1)^2}{(4b_s^2-1)^2}\right] > 0$$

The Northern firm is encouraged to increase its R&D investment. □

The positive impact of the production subsidy on the Northern firm's profit equals its total output: $\partial\pi^j/\partial s = x_n^j + x_s^j > 0$. The Northern firm's domestic sales and exports are greater when its marginal cost is low. The positive impact of the subsidy is greater when $c^j = c^l$. The difference in profit and the R&D investment increases as compared to free trade.

1.4.4. An Import Quota

Consider that the Northern government implements an import quota as under Cournot competition. We still denote by q the maximum level for the Southern firm's exports to the Northern market. Consider that the quota is binding again. Studying the impact of a quota under Bertrand competition is complex because the levels of domestic sales and exports depend on each price. With a binding quota, a competitive situation is moved to a collusive situation (**Harris, 1985**; **Krishna, 1989**; **Karikari, 1991**; **Boccard and Wauthy, 2006**).

Using the Southern firm's free trade demand function for exports, we can express the Southern firm's price of exports as a function of the Northern firm's price of domestic sales and of the Southern firm's exports: $p_n^{*j} = \left(a_n + p_n^j - y_n\right)/b_n$. With a binding quota such as $q < \hat{y}_n$, we have:

$$p_n^{*j}\left(p_n^j, q\right) = \left(a_n + p_n^j - q\right)/b_n\, ; \forall j = \{l, h\} \tag{1.30}$$

The previous expression is the best-response to the Northern firm's price of domestic sales. According to **Karikari (1991)**, when the domestic country implements an import quota, *"the output of the foreign firm is fixed"* and *"an increase in the price of the domestic firm leads to an increase in the price of the foreign price* [p. 232]*."*

The Southern firm no longer maximizes its profit with respect to its price of exports. Such a price only depends on p_n^j and q. The quota has a direct impact on the Southern firm's price of exports and an indirect impact through the Northern firm's price of domestic sales.

The demand function for the Northern firm's domestic sales is now a function of the price p_n and the quota q:

$$x_n^j(p_n, q) = \left[a_n(b_n + 1) - p_n^j(b_n^2 - 1) - q\right]/b_n\, ; \forall j = \{l, h\} \tag{1.31}$$

The profit expressions are:

$$\pi^j = p_n^j x_n^j\left(p_n^j, q\right) + p_s^j x_s^j\left(p_s^j, p_s^{*j}\right) - c^j\left[x_n^j\left(p_n^j, q\right) + x_s^j\left(p_s^j, p_s^{*j}\right)\right] - g x_s^j\left(p_s^j, p_s^{*j}\right); \forall j = \{l, h\} \tag{1.32}$$

$$\pi^{j*} = q p_n^{*j}\left(p_n^j, q\right) + p_s^{*j} y_s^j\left(p_s^j, p_s^{*j}\right) - c^l\left[q + x_s^j\left(p_s^j, p_s^{*j}\right)\right] - g^* q; \forall j = \{l, h\} \tag{1.33}$$

The Northern firm benefits from a from a Stackelberg leadership on its home market (**Harris, 1985**) and selects the two optimal levels of price. The Southern firm only selects the optimal level of the price of domestic sales. The outcome on the Southern country is the same as compared to free trade. The Northern firm's optimal price of domestic sales equals:

$$\hat{p}_n^j(q) = \frac{a_n(b_n+1) + c^j(b_n^2-1) - q}{2(b_n^2-1)}; \forall j = \{l, h\} \tag{1.34}$$

The Northern firm's price of domestic sales increases with a binding quota as compared to free trade. The Southern firm's price of exports is:

$$\hat{p}_n^{j*}(q) = \frac{a_n(b_n+1)(2b_n-1) + c^j(b_n^2-1) - q(2b_n^2-1)}{2b_n(b_n^2-1)}; \forall j = \{l, h\} \tag{1.35}$$

Such a level of price is the Southern firm's best-response on the Northern market. The equilibrium level of the Northern firm's domestic sales equals:

$$\hat{x}_n^j(q) = \frac{a_n(b_n+1) - c^j(b_n^2-1) - q}{2b_n}; \forall j = \{l, h\} \tag{1.36}$$

The Northern firm's domestic sales increase with a binding quota as compared to free trade. The equilibrium levels of profit are:

$$\hat{\pi}^j(q) = \frac{\left[a_n(b_n+1)-c^j(b_n^2-1)-q\right]^2}{4b_n(b_n^2-1)} + \frac{b_s\left[a_s(2b_s+1)-(2b_s^2-1)(c^j+g)+b_s c^l\right]^2}{(4b_s^2-1)^2};$$

$$\hat{\pi}^{*j}(q) = \frac{q\left[a_n(b_n+1)(2b_n-1)+c^j(b_n^2-1)-2b_n(b_n^2-1)(c^l+g^*)-q(2b_n^2-1)\right.}{2b_n(b_n^2-1)} + \frac{b_s\left[a_s(2b_s+1)+b_s(c^j+g)-(2b_s^2-1)c^l\right]^2}{(4b_s^2-1)^2}; \forall j = \{l,h\} \tag{1.37}$$

The Northern firm's profit increases with a binding quota as compared to free trade while the Southern firm's profit decreases because it no longer sets the optimal price of exports. Let us study the impact of the quota on the Northern firm's R&D investment.

We consider the same two cases as under Cournot competition. First, we consider a relatively binding quota that only reduces imports when $c^j = c^h$. Then, we consider a strongly binding quota that is binding regardless of the Northern firm's marginal cost.

Proposition 1.9: Under Bertrand competition, the Northern firm's R&D investment decreases with a relatively binding quota as compared to free trade. With a strongly binding quota, the results are the same compared to Cournot competition if $\overline{q} < \hat{y}_n^l$. A strongly binding quota always increases the R&D investment, otherwise.

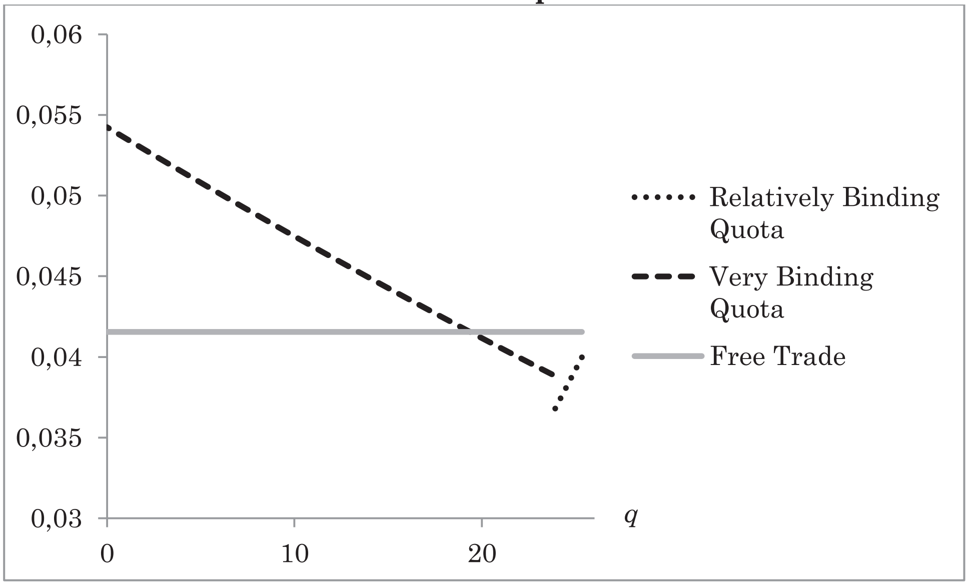
Proof: □ Let us study the two cases:

- First case: a relatively binding quota. The Northern firm's profit only increases when $c^j = c^h$. The difference in profit decreases as compared to free trade.
- Second case: a strongly binding quota. The Northern firm's profit increases regardless of the level of its marginal cost. The difference in profit equals:
  $\pi^l(q) - \pi^h(q) = \frac{(c^h-c^l)[2a_n(b_n+1)-(c^l+c^h)(b_n^2-1)-2q]}{4b_n} + \frac{b_s(2b_s^2-1)(c^h-c^l)[2a_s(2b_s+1)-(2b_s^2-1)(c^l+c^h+2g)+2b_s c^l]}{(4b_s^2-1)^2}$
  There is a non-null quota $\overline{q}$ such as the R&D investment equals the free trade level:
  $\overline{q} = \frac{b_n\{(4b_n^2-1)[\hat{x}_n^l(q=0)+\hat{x}_n^h(q=0)]-2(2b_n^2-1)(\hat{x}_n^l+\hat{x}_n^h)\}}{(4b_n^2-1)} > 0$
  where $\hat{x}_n^l(q=0)$ and $\hat{x}_n^h(q=0)$ denote the level of the Northern firm's domestic sales when the Northern government implements a prohibitive quota such as $q = 0$. Such levels are higher than free trade levels. Nevertheless, it is complex to demonstrate that such a quota is lower than $\hat{y}_n^l$. The results are the same compared to Cournot competition if $\overline{q} < \hat{y}_n^l$. A strongly binding quota always increases the difference in profit, otherwise.

Figure 1.4 illustrates a numerical example as under Cournot competition. We use the same numerical values for parameters and we set: $b_n = b_s = 2$. Under free trade, we have: $\hat{y}_n^l = 18.2667; \hat{y}_n^h = 19.8667$. Here, we find $\overline{q} \approx 19.3689$, with $0 < \overline{q} < \hat{y}_n^l$. Under such a numerical example, the R&D investment decreases with a strongly binding quota as compared to free trade if $q \in (\overline{q}, \hat{y}_n^l)$. It levels off if $q = \overline{q}$. It increases if $q \in [0, \overline{q})$. The results are the same as those of **Costa Cabral, Kujal and Petrakis (1998)** in which the implementation of a quota close to the free trade level reduces the domestic R&D investment. □

-Figure 1.4-

Evolution of the Northern firm's R&D Investment When *q* Varies under Bertrand Competition



Source: authors.
Note: $\alpha(r) = r^k; a_n = 40; a_s = 30; b_n = b_s = 2; c^h = 9; c^l = 3; g = g^* = 1; k = 0.5; v = 500.$

1.4.5. A Minimum price

We now introduce a minimum price implemented by the Northern government. We denote by p_{min} the minimum price such as the Southern firm cannot sell its product on the Northern market at a lower price. Consider that the minimum price is binding i.e. higher than $\hat{p}_n^{*l}$. The profit expressions are:

$$\pi^j = p_n^j x_n^j(p_n^j, p_{min}) + p_s^j x_s^j(p_s^j, p_s^{*j}) - c^j[x_n^j(p_n^j, p_{min}) + x_s^j(p_s^j, p_s^{*j})] - g x_s^j(p_s^j, p_s^{*j}); \forall j = \{l, h\} \quad (1.38)$$

$$\pi^{*j} = p_{min} y_n^j(p_n^j, p_{min}) + p_s^j y_s^j(p_s^j, p_s^{*j}) - c^l[y_n^j(p_n^j, p_{min}) + y_s^j(p_s^j, p_s^{*j})] - g^* y_n^j(p_s^j, p_s^{*j}); \forall j = \{l, h\} \quad (1.39)$$

As the import tariff and the quota, the minimum price has an impact only on the Northern market. Since the minimum price is binding, the Southern firm no longer sets the optimal level of price of exports. The Northern firm's price of domestic sales now equals:

$$\hat{p}_n^j(p_{min}) = \frac{a_n + b_n c^j + p_{min}}{2b_n}; \forall j = \{l, h\} \quad (1.40)$$

The Northern firm's price of domestic sales increases with the minimum price. Therefore, each level of price is higher as compared to free trade on the Northern market.

$$\hat{x}_n^j(p_{min}) = \frac{a_n - b_n c^j + p_{min}}{2}; \hat{y}_n^j(p_{min}) = \frac{a_n(2b_n + 1) + b_n c^j - (2b_n^2 - 1)p_{min}}{2b_n}; \forall j = \{l, h\} \quad (1.41)$$

The Northern (Southern) firm's domestic sales (exports) increase (decrease) with the minimum price.

$$\hat{\pi}^j(p_{min}) = \frac{\left(a_n - b_n c^j + p_{min}\right)^2}{4b_n} + \frac{b_s\left[a_s(2b_s+1) - (2b_s^2-1)(c^j+g) + b_s c^l\right]^2}{\left(4b_s^2-1\right)^2};$$

$$\hat{\pi}^{*j}(p_{min}) = \frac{\left[a_n(2b_n+1) + b_n c^j - (2b_n^2-1)p_{min}\right](p_{min} - c^l - g^*)}{2b_n} + \frac{b_s\left[a_s(2b_s+1) + b_s(c^j+g) - (2b_s^2-1)c^l\right]^2}{\left(4b_s^2-1\right)^2}; \forall j = \{l, h\} \tag{1.42}$$

The Northern firm's profit increases with the minimum price. The Southern firm's profit decreases as compared to free trade because the firm no longer sets the optimal level of price of exports.

Let us consider two cases again. In the first case, the minimum price is relatively binding. In the second case, it is strongly binding.

- First case: $\hat{p}_n^{*l} < p_{min} \leq \hat{p}_n^{*h}$. The minimum price is relatively binding because the Southern firm's price of exports only increases when the Northern firm's marginal cost is low. The Northern firm's profit only increases when its marginal cost is low: $\hat{\pi}^l(p_{min}) > \hat{\pi}^l; \hat{\pi}^h(p_{min}) = \hat{\pi}^h$.
- Second case: $p_{min} > \hat{p}_n^{*h}$. The minimum price is strongly binding because the Southern firm's price of exports increases regardless of the level of the marginal cost. The Northern firm's profit increases under both cases: $\hat{\pi}^l(p_{min}) > \hat{\pi}^l; \hat{\pi}^h(p_{min}) > \hat{\pi}^h$.

Proposition 1.10: The Northern firm's R&D investment increases with the minimum price as compared to free trade. The result holds under both a strongly binding and a relatively binding minimum price.

Proof: □ We study the two cases:

- First case: a relatively binding minimum price. The minimum price is only binding when the Northern firm's marginal cost is low. The Northern firm's profit only increases in such a case. The difference in profit increases with the relatively binding minimum price: $\hat{\pi}^l(p_{min}) - \hat{\pi}^h(p_{min}) > \hat{\pi}^l - \hat{\pi}^h$.
- Second case: a strongly binding minimum price. The minimum price is binding under both cases i.e. the Northern firm's profit increases under both cases. The difference in profit equals:
  $$\hat{\pi}^l(p_{min}) - \hat{\pi}^h(p_{min}) = \frac{b_n(c^h - c^l)\left[2a_n - b_n(c^h + c^l) + 2p_{min}\right]}{4b_n} + \frac{b_s(2b_s^2-1)(c^h - c^l)\left[2a_s(2b_s+1) - (2b_s^2-1)(c^l + c^h + 2g) + 2b_s c^l\right]}{\left(4b_s^2-1\right)^2}$$
  Since the difference in profit increases with a relatively binding minimum price, we have to find the derivative of the difference in profit with respect to p_{min} in order to study the impact of such an instrument as compared to free trade. The difference in profit increases with the strongly binding minimum price:
  $$\frac{\mathrm{d}\left[\hat{\pi}^l(p_{min}) - \hat{\pi}^h(p_{min})\right]}{\mathrm{d}p_{min}} = \frac{(c^h - c^l)}{2} > 0$$
  We have again: $\hat{\pi}^l(p_{min}) - \hat{\pi}^h(p_{min}) > \hat{\pi}^l - \hat{\pi}^h$.

Under both cases, the difference in profit increases with the minimum price as compared to free trade. The Northern firm increases its R&D investment. □

The positive effect of the minimum price on the Northern firm's profit equals: $\partial\pi^j/\partial p_{min} = p_n^j - c^j$. Such a positive impact is greater when its marginal cost is low. This is the reason why the Northern firm is encouraged to increase its R&D investment as compared to free trade.

The results allow us to discuss the difference between a quota and a minimum price. A quota either increases or reduces innovations while a minimum price always increases it. Both instruments reduce competition from a firm that benefit from a competitive advantage. But a relatively binding quota reduces the R&D expenditures because it is only binding when the marginal cost is high. The quota may create a rent such as the Northern firm's profit only increases with a high marginal cost. The relatively binding minimum price is only binding when the marginal cost is low. The Northern firm is encouraged to increase its investment.

1.5. Welfare Analysis

We have studied the impact of several potential policy instruments implemented by the Northern government on the Northern firm's R&D investment. Let us study the economic impact of each policy instrument through the effect on the expected profits, the expected consumer surplus and the expected public revenues. We also analyze the impact on expected national welfares in order to verify whether or not the Northern government is encouraged to implement each policy instrument.

1.5.1. General Framework under Free Trade with Cournot Competition

Consider a concave function for the probability of R&D success: $\alpha(r) = r^k$,with $0 < k \leq 1$. Under free trade, the equilibrium expression of the Northern firm's R&D investment is:

$$\hat{r} = \left[\frac{4(c^h - c^l)(a_n + a_s - c_h - 2g + g^*)}{9v}\right]^{\frac{1}{1-k}}$$

The equilibrium expected profits are:

$$E\left[\widehat{\Pi}(\hat{r})\right] = \hat{r}^k \frac{(a_n - c^l + g^*)^2 + (a_s - c^l - 2g)^2}{9} + \left(1 - \hat{r}^k\right)\frac{(a_n - 2c^h + c^l + g^*)^2 + (a_s - 2c^h + c^l - 2g)^2}{9} - v\hat{r} - F$$

$$E\left[\widehat{\Pi}^*(\hat{r})\right] = \hat{r}^k \frac{(a_n - c^l - 2g^*)^2 + (a_s - c^l + g)^2}{9} + \left(1 - \hat{r}^k\right)\frac{(a_n + c^h - 2c^l - 2g^*)^2 + (a_s + c^h - 2c^l + g)^2}{9} - F^*$$

The expected consumer surpluses are:

$$E\left[\widehat{\mathrm{CS}}(\hat{r})\right] = \hat{r}^k \frac{(a_n - c^l + g^*)^2 + (a_n - c^l - 2g^*)^2}{6} + \left(1 - \hat{r}^k\right)\frac{(a_n - 2c^h + c^l + g^*)^2 + (a_n + c^h - 2c^l - 2g^*)^2}{6}$$

$$E\left[\widehat{\mathrm{CS}}^*(\hat{r})\right] = \hat{r}^k \frac{(a_s - c^l - 2g)^2 + (a_s - c^l + g)^2}{6} + \left(1 - \hat{r}^k\right)\frac{(a_s - 2c^h + c^l - 2g)^2 + (a_s + c^h - 2c^l + g)^2}{6}$$

We suppose that the domestic country's welfare is the un-weighted sum of the domestic firm's profit, domestic consumer surplus and public revenues. The Southern country does not benefit from public revenues since it does not implement any policy instrument. This assumption may be criticized on the basis of political economy's consideration. However, this is the simplest and most straightforward assumption. Under free trade, expected national welfares equal sums of the expected domestic profit and the expected domestic consumer surplus: $E[\widehat{\mathrm{W}}(\hat{r})] = E[\widehat{\Pi}(\hat{r})] + E[\widehat{\mathrm{CS}}(\hat{r})]; E[\widehat{\mathrm{W}}^*(\hat{r})] = E[\widehat{\Pi}^*(\hat{r})] + E[\widehat{\mathrm{CS}}^*(\hat{r})]$.

1.5.2. Discussion

Table 1.1 illustrates the economic impact of each policy instrument.

-Table 1.1-

Economic Impact of Each Policy Instrument

Instrument	r	$E(\Pi)$	$E(\Pi^*)$	$E(\mathrm{CS})$	$E(\mathrm{CS}^*)$	$E(\mathrm{PR})$
Import Tariff	+	+	–	+/–	+	+
Production Subsidy	+	+	–	+	+	–
R&D Subsidy	+	+	–	+	+	–
Import Quota	+/–	+/–	+/–	+/–	+/–	0
Minimum Price	+	+	–	+/–	+	0

Source: author.

Each policy instrument implemented by the Northern government increases the Northern firm's R&D investment except for an import quota. The impact of a quota is ambiguous. Each policy instrument increases (reduces) the Northern (Southern) firm's expected profit. But the effect of a relatively binding quota is ambiguous because it reduces the probability of R&D success.

The effect of an import tariff on the Northern country's expected consumer surplus is ambiguous: there is a negative direct impact by increasing the level of the Northern market price and a positive indirect impact by increasing the probability of R&D success. The total effect may be either positive of negative. The effect on the Southern firm's expected consumer surplus is positive because it increases the probability of R&D success.

The effect of the production subsidy on each expected consumer surplus is positive. The production subsidy has a direct positive impact on the Northern country's consumer surplus by reducing the Northern market price and an indirect positive impact by increasing the probability of R&D success. There is an indirect positive impact on the Southern country's consumer surplus.

The Northern government's R&D subsidy increases each country's expected consumer surplus by increasing the probability of R&D success.

The impact of a minimum price on the Northern country's expected consumer surplus is either positive or negative while the impact on the Southern country's expected consumer surplus is positive.

A relatively binding quota reduces each expected consumer surplus while the effect of a strongly binding quota is ambiguous.

Finally, a production and an R&D subsidy reduce the Northern government's public revenues via further public expenditures while an import tariff increases it. The impact of a quota and a minimum price is null.

1.5.3. Optimal Policy Instruments under Numerical Simulations

A welfare analysis is supposed to specify the optimal level of each instrument, the welfare associated with it, and a selection of the best instrument in terms of achieving the maximum welfare. It looks difficult if not impossible to get general demonstration since the domestic country's welfare is expected based on a probability which is a strictly concave function of R&D. Specific values have been given to parameters.

The values of a and a^* must be high enough such as firms are encouraged to sell on each market. We set: $a_n = 40; a_s = 30$, where $a_n > a_s$ because prices are generally higher in Northern markets owing to an higher market size. We set the following levels of marginal costs: $c^h = 9; c^l = 3$. Each firm's unit transport cost equals one: $g = g^* = 1$. Since the function of the probability of R&D success is concave, we set: $k = 0.5$. We set a high value for the R&D unit cost because the level of R&D investment must be lower than one: $v = 500$. Finally, under Bertrand competition, we set: $b_n = b_s = 2$. Then, we modify the values given to these parameters, considering successively increased and decreased parameter a_s, increased and decreased difference between c^h and c^l, and increased and decreased k (see Appendix 1.C and 1.D). Table 1.2 illustrates the optimal level of each policy instrument when the Northern government maximizes the expected domestic national welfare.

-Table 1.2-

Optimal Policy Instruments

	Instrument	Optimal Value	$\Delta E(\mathrm{W})$	$\Delta E(\mathrm{W}^*)$
Cournot	Import Tariff	17.4999	156.694581	-178.32866
	Production Subsidy	27.9999	555.044276	-6.4969288
	R&D Subsidy	56.5217391	0.15022222	-1.51377778
	Import Quota	0	162.153667	-180.498222
Bertrand	Import Tariff	16.3249918	176.231066	-265.452474
	Production Subsidy	2.8110735	6.26554886	-22.7749721
	R&D Subsidy	86.0051985	0.89662009	-1.90842309
	Import Quota	0	65.8124372	-313.056386
	Minimum price	16.6666667	0.15202836	-0.18499058

Source: author.
Note: $a_n = 40; a_s = 30; b_n = b_s = 2; c^h = 9; c^l = 3; g_n = g_s = 1; k = 0.5; v = 500$.

Each Policy instrument implemented by the Northern government increases (decreases) the Northern (Southern) country's expected national welfare. We can compare each policy instrument.

- Under Cournot competition, the best instrument seems to be the production subsidy. But under Bertrand competition, it is the import tariff. Bertrand competition is too competitive compared to Cournot competition. Under Bertrand, a production subsidy involves a high drop in the Northern firm's prices. The demand for the Northern firm's product increases sharply. Public expenditures become too high. They lower the positive effect on the Northern national welfare compared to an import tariff.

- The optimal quota is always prohibitive because: (i) it removes competition from the Southern country; (ii) it always increases the Northern firm's R&D investment. Nevertheless, there is a negative effect on the Northern country's consumer surplus by reducing the total supply. Furthermore, it does not involve further public revenues compared to a tariff. This is the reason why the prohibitive quota is never the best instrument.
- The minimum price is never the best instrument for the same reasons. The effect on public revenues is null and there is a negative effect on the consumer surplus. But a minimum price is worse than a prohibitive quota because it does not remove competition from the Southern country. It only increases the Southern firm's price of exports. The minimum price may reduce the Northern country's national welfare under several cases.
- The R&D subsidy is always worse than the tariff and the production subsidy. In the selected framework, an R&D subsidy only affects (positively) the probability of R&D success, here denoted by $\alpha(r)$. Indeed, the R&D subsidy decreases the domestic firm's total cost, in particular its R&D cost. But in terms of public revenues, it costs exactly the same amount such that the domestic welfare is unchanged. In particular, an R&D subsidy does not change the domestic firm's output (in the Cournot case) or its price (in the Bertrand case) once the domestic firm's marginal cost is known. It only modifies the R&D implemented by the domestic firm and consequently, the probability of reaching a low marginal cost.

These results hold when parameters vary (see Appendix 1.C and 1.D). Therefore, we can conclude that the Northern country's favorite instrument is the production subsidy under Cournot competition and the import tariff under Bertrand competition.

1.6. Concluding Remarks

The objective of this chapter was to evaluate the potential impact of various "at-the-border" and "behind-the-border" policy instruments on local R&D. From a theoretical point of view, this chapter is based on a duopolistic model (under either Bertrand or Cournot competition) with a specific feature (compared to the literature); the impact of R&D is uncertain. The R&D investment increases the probability of R&D success, which we think is a realistic assumption. In that sense, this chapter is largely innovative. The analysis of the impact of an import quota and of a minimum price on R&D is particularly innovative.

Each policy instrument increases the Northern firm's R&D investment except for an import quota (and a VER). As a consequence, policy instruments are ways to support domestic firms that face growing competition from low costs countries. As we have mentioned in the general introduction, the empirical economic literature has also illustrated a positive impact of direct supports and tax cuts (**Mansfield, 1986**; **Berger,** 1993; Hall, 1993; Bloom et al., 2002). Nevertheless, we realize that there is no empirical evidence on the negative impact of an import quota.

Another way of enhancing local R&D is to improve the quality of the environment in terms of law, property rights, knowledge diffusions, inventions, and innovations from (public and private) research centers to the private sector. An illustration is the US Bayh-Dole Act in 1980 which changed the ownership of inventions made with federal funding. In our model, this structural policy would imply a modification of the probability of successful R&D. The function would become more convex. Each dollar spent in R&D would lead to a more probable drop in the marginal production cost.

What is the best instrument amongst all those considered here? We concluded on the superiority, in terms of welfare, of the production subsidy under Cournot and of the import tariff under Bertrand. This conclusion deserves a discussion. First, it is based on a specific government's objective function. The specification of a government's objective is always arbitrary since it is difficult to state the importance of consumer surplus, profits, and public revenues in a political process. Second, an important aspect of R&D expenditures is externalities, which should be included in governments' objective. Third, dynamic considerations matter since R&D expenditures may have a long-term impact on competitiveness. If we consider a game over several periods, a failure of R&D today may reinforce the attractiveness of R&D tomorrow, while a success of R&D today may weaken a government's interest in such expenditures tomorrow.

R&D subsidies are an appealing policy instrument because their impact on R&D investments is systematically positive regardless of the form of demand functions. Furthermore, R&D subsidies may be more easily implemented than other policies. The use of instruments like quotas is forbidden by the WTO and the use of tariffs is not totally free. They are bound. Production subsidies are not prohibited since according to the WTO law, they are "actionable" but their implementation is under severe control since they may be implemented in specific circumstances for a limited period of time. Instruments like R&D subsidies and minimum price are not prohibited by the WTO as long as they do not have a negative impact on international trade. It may be difficult to demonstrate that a policy like an R&D subsidy has a negative impact on trade flows. Even if it is the case, international institutions are relatively tolerant. For example, in 2012, the European Commission approved a French state assistance in the car sector even though it concluded that the measure would affect international trade flows (Evenett, 2013). In our model, we show that these policies have a negative impact on international trade, but they are "behind-the-border" policies and therefore are much less visible. The WTO members are not obligated to notify the implementation of such policies, unlike changes in tariffs and the implementation of quotas ("at-the-border" policies), which do have to be brought to the attention of the WTO.

Appendix to Chapter 1

1.A. General Forms for Demand Functions under Cournot Competition

Using general forms, we have:

$$\frac{\mathrm{d}\hat{\pi}^j}{\mathrm{d}t} = \frac{\hat{x}_n^j \pi_{x_n x_n}^j \pi_{x_n y_n}^j}{D_n^j} > 0$$

$$\frac{\mathrm{d}\hat{\pi}^j}{\mathrm{d}s} = \frac{\hat{x}_n^j \pi_{x_n x_n}^j \pi_{y_n y_n}^{*j}}{D_n^j} + \frac{\hat{x}_s^j \pi_{x_s x_s}^j \pi_{y_s y_s}^{*j}}{D_s^j} > 0$$

Under linear demand function, the only terms that depend on c^j are $\hat{x}_n^j$ and $\hat{x}_s^j$. In Section 1.2, we proved that the Northern firm's domestic sales and exports decrease with its marginal cost. The positive effect of s and t on π^j is greater when $c^j = c^l$. The production subsidy and the tariff implemented by the Northern government increase the difference in profit. But under nonlinear demand function, it is complex to find general results because each term depends on c^j. In this case, each instrument may increase or decrease the difference in profit. Nevertheless, we did not find any nonlinear example in which the effects of s and t are negative.

1.B. General Forms for Demand Functions under Bertrand Competition

We have:

$$\frac{\mathrm{d}\pi^j}{\mathrm{d}t} = \left(\hat{p}_n^j - c^j\right) \frac{y_{n p_n^*}^j \pi_{p_n p_n}^j \pi_{p_n p_n^*}^j}{B_n^j} > 0$$

$$\frac{\mathrm{d}\pi^j}{\mathrm{d}s} = -\left[x_{n_{p_n}}^j \left(\hat{p}_n^j - c^j + s\right)\left(1 - \frac{\pi_{p_n p_n^*}^j \pi_{p_n^* p_n}^{*j}}{B_n^j}\right) + x_{s_{p_s}}^j \left(\hat{p}_s^j - c^j + s\right)\left(1 - \frac{\pi_{p_s p_s^*}^j \pi_{p_s^* p_s}^{*j}}{B_s^j}\right)\right] > 0$$

Under linear forms, the only terms that depend on c^j are $\left(\hat{p}_n^j - c^j\right)$ and $\left(\hat{p}_s^j - c^j\right)$. Such terms are lower when the marginal cost increases. The positive impact of the tariff and the production subsidy is higher when $c^j = c^l$. The difference in profit increases with an import tariff and with a production subsidy. Nevertheless, under nonlinear forms, other terms also depend on c^j. It is complex to conclude. The effect may be either positive or negative.

1.C. Welfare Analysis under Cournot Competition

-Table 1.3-

Optimal Policy Instruments When Parameters Vary (Cournot Competition)

	Instrument	Optimal Value	$\Delta E(\mathrm{W})$	$\Delta E(\mathrm{W}^*)$
$\Delta a_s = 10$	Import Tariff	17.4999	158.250128	-177.395332
	Production Subsidy	34.9999	854.260938	76.4230361
	R&D Subsidy	48.1481462	0.15022222	-1.62933326
	Import Quota	0	163.495889	-179.258222
$\Delta a_s = 20$	Import Tariff	17.4999	159.805675	-176.462004
	Production Subsidy	34.9999	940.127359	77.667477
	R&D Subsidy	41.9354726	0.15022222	-1.74488838
	Import Quota	0	164.838111	-178.018222
$\Delta c^h = -3$	Import Tariff	17.4999	178.371131	-158.040433
	Production Subsidy	27.9999	632.529389	34.7377213
	R&D Subsidy	64.0535365	0.06234722	-0.43736111
	Import Quota	0	184.483229	-158.692764
$\Delta c^h = 3$	Import Tariff	17.4999	137.872455	-198.725781
	Production Subsidy	27.9999	496.250615	-41.6587988
	R&D Subsidy	46.5994954	0.171125	-2.67324995
	Import Quota	0	137.72484	-202.872486
$\Delta c^l = -2$	Import Tariff	18.5	164.930012	-210.170963
	Production Subsidy	29.9999	609.762918	-15.8114829
	R&D Subsidy	50.6607919	0.20898765	-2.6532345
	Import Quota	0	167.795395	-213.274568
$\Delta c^l = 2$	Import Tariff	16.4999	150.555727	-148.325469
	Production Subsidy	25.9999	515.71914	8.33458123
	R&D Subsidy	62.2317335	0.08306173	-0.66449351
	Import Quota	0	156.644432	-149.476642
$\Delta k = 0.25$	Import Tariff	17.4999	147.419237	-182.872629
	Production Subsidy	27.9999	500.471542	-20.3797781
	R&D Subsidy	56.5217322	0.03059891	-0.32115396
	Import Quota	0	154.954443	-186.476677
$\Delta k = -0.25$	Import Tariff	17.4999	172.368071	-165.445103
	Production Subsidy	27.9999	616.251901	22.6681564
	R&D Subsidy	56.5217322	0.14623855	-1.45425606
	Import Quota	0	175.816914	-166.68535

Source: author.

Note: $a_n = 40; a_s = 30; c^h = 9; c^l = 3; g_n = g_s = 1; k = 0.5; v = 500.$

1.D. Welfare Analysis under Bertrand Competition

-Table 1.4-

Optimal Policy Instruments When Parameters Vary (Bertrand Competition)

	Instrument	Optimal Value	ΔE(W)	ΔE(W*)
$\Delta a_s = 10$	Import Tariff	16.3641356	177.077206	-264.831061
	Production Subsidy	2.5797741	5.27689128	-19.5340494
	R&D Subsidy	74.6802106	0.89662009	-1.79549866
	Import Quota	0	67.4581528	-311.513453
	Minimum price	16.6666667	0.11307724	-0.11139058
$\Delta a_s = 20$	Import Tariff	16.4032794	177.925372	-264.203631
	Production Subsidy	2.34847488	4.37307218	-16.5382484
	R&D Subsidy	65.9906898	0.89662009	-1.68257417
	Import Quota	0	69.1038684	-309.970519
	Minimum price	16.6666667	0.07412613	-0.03779058
$\Delta c^h = -3$	Import Tariff	16.6403524	183.304051	-259.148738
	Production Subsidy	3.16770375	7.7086204	-20.3069075
	R&D Subsidy	87.5338215	0.27128969	-0.46058685
	Import Quota	0	80.9602001	-298.829647
	Minimum price	16.2666667	0.02671674	0.00505662
$\Delta c^h = 3$	Import Tariff	16.1090108	171.288797	-271.141505
	Production Subsidy	2.59467535	5.6148374	-25.4347352
	R&D Subsidy	84.2074094	1.6336328	-4.33729984
	Import Quota	0	53.0880204	-325.311563
	Minimum price	17.0666667	0.42144425	-0.839548
$\Delta c^l = -2$	Import Tariff	17.1471747	194.210721	-298.888101
	Production Subsidy	2.88264153	6.80123247	-26.9124797
	R&D Subsidy	84.2026818	1.58196875	-3.77592537
	Import Quota	0	50.9386172	-381.878863
	Minimum price	15.6	0.31702155	-0.55554402
$\Delta c^l = 2$	Import Tariff	15.5737218	160.512892	-233.569325
	Production Subsidy	2.83981947	6.24697585	-19.3026191
	R&D Subsidy	87.8720873	0.40151482	-0.75164362
	Import Quota	0	66.1957339	-272.127866
	Minimum price	17.7333333	0.05597551	-0.02925353
$\Delta k = 0.25$	Import Tariff	16.106178	171.611904	-267.385802
	Production Subsidy	2.49764147	4.79965447	-21.6266148
	R&D Subsidy	86.0051939	0.43216462	-0.98121932
	Import Quota	0	56.9989457	-319.848486
	Minimum price	16.6666667	0.13093983	-0.15876898
$\Delta k = -0.25$	Import Tariff	16.5807505	181.896113	-261.102683
	Production Subsidy	3.1116528	7.6145443	-21.5736699
	R&D Subsidy	86.0051939	0.65573436	-1.36705455
	Import Quota	0	76.8587753	-302.676564
	Minimum price	16.6666667	-0.21302942	0.25437606

Source: author.
Note: $a_n = 40; a_s = 30; b_n = b_s = 2; c^h = 9; c^l = 3; g_n = g_s = 1; k = 0.5; v = 500$.

-CHAPTER 2-

Policy Instruments, Product Research and Development, Vertical Differentiation, and Uncertainty in a North-South Duopoly[15]

2.1. Introduction

The increase in non-price competitiveness is another crucial issue for high income countries. For example, Switzerland tops the Global Competitiveness Index 2014-2015 in terms of *"Innovation and Sophistication Factors"* owing to high expenditures in R&D by both domestic firms and institutions (**Schwab, 2014**).

Product innovations measured by product R&D investments may significantly influence the features of finished goods. Firms may invest in R&D in order to increase product quality. Vertical differentiation represents a way to face competition from low-cost countries.

There is still some debate about the role of policy instruments in the increase of non-price competitiveness (see the review of the economic literature on product R&D in Chapter 0, Subsection 0.4.2). Therefore, the study of the impact of such instruments on product R&D expenditures is really important.

In this chapter, we design the same North-South duopoly in which firms with asymmetric production costs compete on both markets. But we focus on Bertrand competition. The Northern firm invests in product R&D in order to differentiate its product compared to that of the Southern competitor. The outcome of this investment is also uncertain. If successful, the Northern firm produces a higher-quality version of the same good. If unsuccessful, then, no quality improvement is implemented. Our modeling of uncertainty is based on Chapter 1. We believe it yields more realistic results, which is one of the contributions of this chapter to the existing literature.

We study the impact of the implementation of the same policy instruments by the Northern government as in Chapter 1. We also study the impact of a further instrument: a quality standard. A good example of quality standards in the automobile industry is the ISO technical specification ISI/TS16949 aimed at quality improvement and defect prevention.

Our model involves a three-stage game. First, the Northern firm's government selects the optimal level of the policy instrument level by anticipating the Northern firm's product R&D investment and levels of price. Second, the Northern firm decides on the optimal product R&D investment that maximizes its expected profit. In the final stage, firms set their levels of price.

[15] This chapter has been written with another PhD candidate, Viola Lamani (LAREFI, University of Bordeaux) and published in a *LAREFI Working Paper* (**Berthoumieu and Lamani, 2016**).

The main finding of our analysis is that each policy instrument increases the Northern firm's R&D expenditure except for the import quota. Therefore, a government whose only aim is to enhance non-price competitiveness by encouraging product R&D investments should implement one of these policy instruments. Nevertheless, the latter may have opposite effects on the expected consumer surplus, public revenues and welfare. We illustrate this result through numerical simulations.

The rest of this chapter is organized as follows. Section 2.2 describes the theoretical model. Section 2.3 presents an example under linear demand functions. Section 2.4 analyzes the impact of six different policy instruments on the Northern firms' R&D investment. Section 2.5 conducts a welfare analysis and compares the efficiency of the policy instruments. Section 2.6 concludes.

2.2. General Framework

Consider the same North-South duopoly as in Chapter 1 with two segmented markets.

Assumption 2.1: There is Bertrand competition on each market. Firms select the optimal levels of price.

Now, the Northern firm invests in product R&D (instead of process R&D) in order to increase the quality of its product compared to that of the Southern firm. The framework also relates to the automobile industry in which firms also innovate in terms of product by investing in product R&D. As we said previously, the economic literature shows that firms invest more in product R&D than in process R&D for high-tech industries (**Scherer and Ross, 1990**; **Fritsch and Meschede; 2001**; **Park, 2001**; **Toshimitsu, 2003**; **Jinji and Toshimitsu, 2013**). R&D expenditures are generally higher for Northern firms compared to Southern firms. It explains why the quality of Northern automobile firms' vehicles is generally higher compared to Southern automobile firms'.

The outcome of the Northern firm's R&D investment is again uncertain. If successful, two different quality levels of the same commodity variety are on markets. We denote by ϕ the degree of differentiation between the two products. In this case, $\phi > 0$. If unsuccessful, goods produced by both firms are similar in terms of quality if R&D. In this case, $\phi = 0$. In this model, there are two levels of quality. The Northern firm does not select an optimal level of quality. It only invests in R&D in order to benefit from the vertical differentiation.

Consider a probability of R&D success. We use the superscript d to denote the case of a successful R&D (i.e. with vertical differentiation) and the superscript h, otherwise. For example, p_n^d (p_n^h) denotes the Northern firm's price of domestic sales when the R&D outcome is successful (unsuccessful).

Assumption 2.2: The probability of R&D success is still denoted by α. The probability that the R&D investment fails is $(1-\alpha)$. The probability of success depends on the R&D investment level denoted by r: $\alpha = \alpha(r)$. It increases with the R&D level: $\alpha'(r) > 0$. Nevertheless, the returns are decreasing: $\alpha''(r) \leq 0$.

The economic literature has also considered decreasing returns for R&D expenditures. A product R&D investment is an investment in knowledge. A good example is labor training that ensures the increase in the quality of the output. In this case, decreasing returns mean that the marginal effect of training may decrease over time. This assumption is really important since it influences a broad set of our results, in particular the impact of any policy instrument on the Northern firm's R&D.

The total cost of the Northern firm's R&D investment is vr, where v denotes the unit cost of the R&D investment. The Northern firm faces such a cost regardless of the R&D outcome.

When no trade policy instrument is implemented, our model involves a two-stage game. First, the Northern firm selects the level of R&D investment that maximizes its expected profit by anticipating the levels of price. Second, each firm sets the levels of price that maximize its profit. The equilibrium solution is obtained by backward induction from the second stage of price competition. We analyze separately the case in which the R&D outcome is successful, and subsequently in which it is unsuccessful.

2.2.1. Successful R&D

First, consider the case of a successful R&D investment. We use the superscript d for each variable. Goods are vertically differentiated.

Assumption 2.3: Firms produce vertically differentiated goods. Consumers have a preference for quality denoted by θ that increases with ϕ: $\theta = \theta(\phi)$. To simplify the demonstration, consider that the preference for quality is the same for each consumer in both the North and the South. The demand for a given good depends on each price and on the preference for quality: $x_i^d = x_i^d\left[p_i^d, p_i^{*d}, \theta(\phi)\right]; y_i^d = y_i^d\left[p_i^d, p_i^{*d}, \theta(\phi)\right]; \forall i = \{n, s\}$. The demand for the Northern (Southern) firm's product increases (decreases) with the degree of differentiation: $\partial x_i^d/\partial\phi > 0; \partial y_i^d/\partial\phi < 0$.

We denote by C^d (C^{*d}) the Northern (Southern) firm's total production cost. Consider linear total production costs functions such as marginal costs are constant. We denote by c^d (c^*) the Northern (Southern) firm's marginal cost. The level of c^* does not depend on the R&D outcome.

Assumption 2.4: The Northern firm's production cost depends on the degree of vertical differentiation. Producing a high quality good is costly: $\partial C^d/\partial\phi > 0$. The marginal cost also depends on the degree of vertical differentiation and increases with it: $c^d = c^d(\phi); \mathrm{d}c^d/\mathrm{d}\phi > 0$.

The economic literature considers that quality improvement influences either variable costs or fixed costs (**Maskus et al., 2013**; **Cheng, 2014**). Here, we consider an endogenous variable cost for the Northern firm. Its marginal cost increases with its level of quality. The total cost functions are the following:

$$C^d = c^d(\phi)\{x_n^d[p_n^d, p_n^{*d}, \theta(\phi)] + x_s^d[p_s^d, p_s^{*d}, \theta(\phi)]\} + gx_s^d[p_s^d, p_s^{*d}, \theta(\phi)] + F$$

$$C^{*d} = c^*\{y_n^d[p_n^d, p_n^{*d}, \theta(\phi)] + y_s^d[p_s^d, p_s^{*d}, \theta(\phi)]\} + g^*y_n^d[p_n^d, p_n^{*d}, \theta(\phi)] + F^*$$

Π^d (Π^{*d}) denotes the Northern (Southern) firm's profit with a successful R&D i.e. with vertical differentiation. To simplify profit expressions, we set: $x_n^d = x_n^d[p_n^d, p_n^{*d}, \theta(\phi)]$; $x_s^d = x_s^d[p_s^d, p_s^{*d}, \theta(\phi)]$; $c^d = c^d(\phi)$; $y_n^d = y_n^d[p_n^d, p_n^{*d}, \theta(\phi)]$; $y_s^d = y_s^d[p_s^d, p_s^{*d}, \theta(\phi)]$. We have:

$$\Pi^d = p_n^d x_n^d + p_s^d x_s^d - c^d\left(x_n^d + x_s^d\right) - g x_s^d - F - vr \quad (2.1)$$

$$\Pi^{*d} = p_n^{*d} y_n^d + p_s^{*d} y_s^d - c^*\left(y_n^d + y_s^d\right) - g^* y_n^d - F^* \quad (2.2)$$

2.2.2. Unsuccessful R&D

Consider now the case in which the R&D is unsuccessful. We use the superscript h for each variable. We denote by C^h (C^{*h}) the Northern (Southern) firm's total production cost. The parameter c^h denotes the Northern firm's constant marginal cost. According to Assumption 2.4, we have: $c^d(\phi) > c^h$. The Northern firm's total production cost no longer depends on the degree of vertical differentiation. Demand functions only depend on prices (see Assumption 1.5 in Chapter 1).

Profit expressions are the following:

$$\Pi^h = p_n^h x_n^h + p_s^h x_s^h - c^h\left(x_n^h + x_s^h\right) - g x_s^h - F - vr \quad (2.3)$$

$$\Pi^{*h} = p_n^{*h} y_n^h + p_s^{*h} y_s^h - c^*\left(y_n^h + y_s^h\right) - g^* y_n^h - F^* \quad (2.4)$$

2.2.3. Choice of R&D Investment

Assumption 2.5: The Northern firm is encouraged to differentiate its product with respect to the product of its competitor. The Northern firm's profit increases with the degree of differentiation: $\mathrm{d}\pi^d/\mathrm{d}\phi > 0$. The profit is greater in case of a successful R&D: $\pi^d > \pi^h$. The Northern firm would not be encouraged to invest in R&D, otherwise. We also consider that the marginal profit is stronger when the R&D is successful: $p_i^d - c^d > p_i^h - c^h, \forall i = \{n, s\}$.

The Northern firm's expected profit is:

$$E[\Pi(r)] = \alpha(r)\hat{\pi}^d + [1 - \alpha(r)]\hat{\pi}^h - F - vr \quad (2.5)$$

The Northern firm selects the optimal R&D investment level that maximizes such an expected profit. From the first order condition, we have:

$$\alpha'(r) = v/\left(\hat{\pi}^d - \hat{\pi}^h\right) \quad (2.6)$$

A simple interpretation of the previous equation stems from rewriting the Northern firm's R&D investment as a function of the difference in profit $\left(\hat{\pi}^d - \hat{\pi}^h\right)$ and of the R&D unit cost v: $r = \psi\left[v, \left(\hat{\pi}^d - \hat{\pi}^h\right)\right]$, with $\partial\psi/\partial\left(\hat{\pi}^d - \hat{\pi}^h\right) > 0; \partial\psi/\partial v < 0$. Therefore, we can study the impact of policy instruments on the R&D investment by analyzing its impact on the difference in profit.

2.3. Equilibrium with Specific Linear Demand Functions

Let us use now linear examples for demand functions and total cost functions for an easier demonstration. First, consider the following function of consumers' preference for quality on each market:

$$\theta(\phi) = \phi\eta \tag{2.7}$$

The parameter η denotes the sensitivity of the preference for quality with respect to the degree of differentiation, with $0 < \eta \leq 1$. Demands now depend on $\phi\eta$. For each market i, we set the following demand functions:

$$x_i = \begin{cases} x_i^h\left(p_i^h, p_i^{*h}\right) = a_i - b_i p_i^h + p_i^{*h}, \text{ if } \phi = 0 \\ x_i^d\left(p_i^d, p_i^{*d}, \phi\eta\right) = a_i(1+\phi\eta) - b_i(1-\phi\eta)p_i^d + (1+\phi\eta)p_i^{*d}, \text{otherwise.} \end{cases} \tag{2.8}$$

$$y_i = \begin{cases} y_i^h\left(p_i^h, p_i^{*h}\right) = a_i + p_i^h - b_i p_i^{*h}, \text{if } \phi = 0 \\ y_i^d\left(p_i^d, p_i^{*d}, \phi\eta\right) = a_i(1-\phi\eta) + (1-\phi\eta)p_i^d - b_i(1+\phi\eta)p_i^{*d}, \text{otherwise.} \end{cases} \tag{2.9}$$

The parameter a_i denotes the fixed part of demand functions that does not depend on prices and quality. The parameter b_i denotes the horizontal differentiation between the two goods on the market i. We have: $b_i > 1$. Under the unsuccessful case, each demand is more sensitive to the domestic firm's price compared to the foreign firm's price. Under the successful case, the following condition is necessary: $b_i > (1+\phi\eta)/(1-\phi\eta)$.

Note that in previous studies, authors first set a utility function to infer demand functions (**Sutton, 1997**; **Symeonidis, 2003**). Our methodology is reversed. We first set demand functions. The expression of consumer surplus is then given by integrating the demand functions. The consumer surplus increases with $\phi\eta$ (**Mussa and Rosen, 1978**).

Each firm selects the optimal levels of price that maximize its profit. Under a successful R&D, we have:

$$\hat{p}_n^d = \frac{a_n(2b_n+1)+2b_n^2c^d(\phi)+b_n(c^*+g^*)+\phi\eta\left[a_n(2b_n-1)-2b_n^2c^d(\phi)+b_n(c^*+g^*)\right]}{\left(4b_n^2-1\right)(1-\phi\eta)};$$

$$\hat{p}_n^{*d} = \frac{a_n(2b_n+1)+b_nc^d(\phi)+2b_n^2(c^*+g^*)-\phi\eta\left[a_n(2b_n-1)+b_nc^d(\phi)-2b_n^2(c^*+g^*)\right]}{\left(4b_n^2-1\right)(1+\phi\eta)};$$

$$\hat{p}_s^d = \frac{a_s(2b_s+1)+2b_s^2\left[c^d(\phi)+g\right]+b_sc^*+\phi\eta\left[a_s(2b_s-1)-2b_s^2\left(c^d(\phi)+g\right)+b_sc^*\right]}{\left(4b_s^2-1\right)(1-\phi\eta)};$$

$$\hat{p}_s^{*d} = \frac{a_s(2b_s+1)+b_s\left[c^d(\phi)+g\right]+2b_s^2c^*-\phi\eta\left[a_s(2b_s-1)+b_s\left(c^d(\phi)+g\right)+2b_s^2c^*\right]}{\left(4b_s^2-1\right)(1+\phi\eta)} \tag{2.10}$$

The Northern (Southern) firm's prices increase (decrease) with the degree of differentiation. When two goods are vertically differentiated, the higher quality good is more expensive. The difference in price between the two goods increases with the degree of differentiation.

The levels of domestic sales and exports for each firm are:

$$\hat{x}_n^d = \frac{b_n\{a_n(2b_n+1)-(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)+\phi\eta[a_n(2b_n-1)+(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)]\}}{(4b_n^2-1)};$$

$$\hat{y}_n^d = \frac{b_n\{a_n(2b_n+1)+b_nc^d(\phi)-(2b_n^2-1)(c^*+g^*)-\phi\eta[a_n(2b_n-1)+b_nc^d(\phi)+(2b_n^2-1)(c^*+g^*)]\}}{(4b_n^2-1)};$$

$$\hat{x}_s^d = \frac{b_s\{a_s(2b_s+1)-(2b_s^2-1)[c^d(\phi)+g]+b_sc^*+\phi\eta[a_s(2b_s-1)+(2b_s^2-1)(c^d(\phi)+g)+b_sc^*]\}}{(4b_s^2-1)};$$

$$\hat{y}_s^d = \frac{b_s\{a_s(2b_s+1)+b_s[c^d(\phi)+g]-(2b_s^2-1)c^*-\phi\eta[a_s(2b_s-1)+b_s(c^d(\phi)+g)+(2b_s^2-1)c^*]\}}{(4b_s^2-1)} \tag{2.11}$$

Finally, consider that each firm's profit equals the sum of the profit earned on the domestic market and the profit earned on the foreign market: $\hat{\pi}^d = \hat{\pi}_n^d + \hat{\pi}_s^d; \hat{\pi}^{*d} = \hat{\pi}_n^{*d} + \hat{\pi}_s^{*d}$. We have:

$$\hat{\pi}_n^d = \frac{b_n\{a_n(2b_n+1)-(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)+\phi\eta[a_n(2b_n-1)+(2b_n^2-1)c^d(\phi)+b_n(c^*+g^*)]\}^2}{(4b_n^2-1)^2(1-\phi\eta)};$$

$$\hat{\pi}_s^d = \frac{b_s\{a_s(2b_s+1)-(2b_s^2-1)[c^d(\phi)+g]+b_sc^*+\phi\eta[a_s(2b_s-1)+(2b_s^2-1)(c^d(\phi)+g)+b_sc^*]\}^2}{(4b_s^2-1)^2(1-\phi\eta)};$$

$$\hat{\pi}_n^{*d} = \frac{b_n\{a_n(2b_n+1)+b_nc^d(\phi)-(2b_n^2-1)(c^*+g^*)-\phi\eta[a_n(2b_n-1)+b_nc^d(\phi)+(2b_n^2-1)(c^*+g^*)]\}^2}{(4b_n^2-1)^2(1+\phi\eta)};$$

$$\hat{\pi}_s^{*d} = \frac{b_s\{a_s(2b_s+1)+b_s[c^d(\phi)+g]-(2b_s^2-1)c^*-\phi\eta[a_s(2b_s-1)+b_s(c^d(\phi)+g)+(2b_s^2-1)c^*]\}^2}{(4b_s^2-1)^2(1+\phi\eta)} \tag{2.12}$$

According to Assumption 2.5, the Northern (Southern) firm's profit increases (decreases) with the degree of differentiation. Therefore, the difference in profit $(\hat{\pi}^d - \hat{\pi}^h)$ is positive.

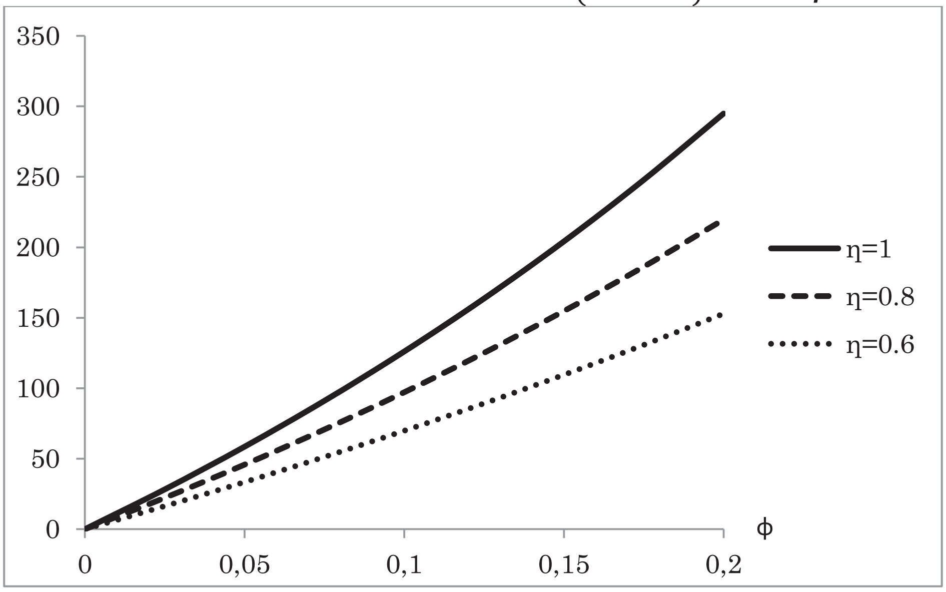
Under an unsuccessful R&D, we can find equilibrium expressions of prices, outputs and profits by setting $\phi = 0$ and $c^d(\phi) = c^h$.

Figure 2.1 illustrates the positive impact of the degree of differentiation on the difference in profit mentioned in Assumption 2.5 with numerical values: $c^d(\phi) = c^h + \phi; a_n = 40; a_s = 30; b_n = b_s = 2; c^h = 6; c^* = 3; g = g^* =; F = F^* = 0$. The positive impact increases with η.

The Northern firm selects the optimal level of R&D investment that maximizes its expected profit by taking into account the previous results. We know now the expressions of $\hat{\pi}^d$and $\hat{\pi}^h$. We use the same function for the probability of R&D success: $\alpha(r) = r^k$,with $0 < k \leq 1$.

-Figure 2.1-

Evolution of the Difference in Profit $(\hat{\pi}^d - \hat{\pi}^h)$ When ϕ Varies



Source: authors.
Note: We set: $c^d(\phi) = c^h + \phi; a_n = 40; a_s = 30; b_n = b_s = 2; c^h = 6; c^* = 3; g = g^* =; F = F^* = 0$.

2.4. Policy Instruments Implemented by the Northern Government

Let us study the impact of six policy instruments: an import tariff, a production subsidy, an R&D subsidy, a quality standard, a minimum price and an import quota. The Northern government may justify the implementation of these instruments by the increasing competition from an emerging country that benefits from a competitive advantage. Policy instruments aim to enhance the Northern firm's non-price competitiveness by increasing the probability of a successful R&D outcome and to increase the Northern country's national welfare. The structure of the model is the same compared to Chapter 1 (see Figure 1.3). The Northern government implements trade policy instruments that maximize the expected national welfare. We use the same function of expected national welfare as in Chapter 1. It depends on the domestic profit, the domestic consumer surplus and the domestic public revenues.

First, we look for the equilibrium levels of price. Then, we evaluate the impact of each policy instrument on the R&D investment. Finally, we find the optimal level for each policy instrument (see Section 2.5).

2.4.1. An Import Tariff

Consider that the Northern government implements an import tariff. The Southern firm's profit expression changes as compared to free trade:

$$\pi^* = \begin{cases} \pi^{*h} = p_n^{*h} y_n^h + p_s^{*h} y_s^h - c^*\left(y_n^h + y_s^h\right) - (t + g^*) y_n^h, \text{ if } \phi = 0 \\ \pi^{*d} = p_n^{*d} y_n^d + p_s^{*d} y_s^d - c^*\left(y_n^d + y_s^d\right) - (t + g^*) y_n^d, \text{ otherwise.} \end{cases} \tag{2.13}$$

Proposition 2.1: Under the specific functions, the Northern firm's R&D investment increases with its domestic government's import tariff as compared to free trade.

Proof: □ Let us study the impact of the tariff on the difference in profit $[\hat{\pi}^d(\phi,\eta,t) - \hat{\pi}^h(t)]$. Note that the derivative of the difference is the difference of the derivatives:

$$\frac{\mathrm{d}[\hat{\pi}^d(\phi,\eta,t)-\hat{\pi}^h(t)]}{\mathrm{d}t} = \frac{\mathrm{d}\hat{\pi}^d(\phi,\eta,t)}{\mathrm{d}t} - \frac{\mathrm{d}\hat{\pi}^h(t)}{\mathrm{d}t}$$

Furthermore, we already know that the Northern firm's profit increases with the tariff regardless of the outcome of the R&D. We can study the impact of the degree of vertical differentiation on the positive impact of the tariff on the Northern firm's profit. Then, we have to study the sign of the second derivative $\mathrm{d}^2\hat{\pi}^d(\phi,\eta,t)/(\mathrm{d}t\mathrm{d}\phi)$. In this case, we analyze the impact of an increase in ϕ from 0 to 1 on $\mathrm{d}\hat{\pi}^d(\phi,\eta,t)/\mathrm{d}t$. A positive result means that the positive impact of the tariff is higher when $\phi = 1$ compared to the unsuccessful case in which $\phi = 0$. To simplify expressions, we set: $\hat{\pi}^d = \hat{\pi}^d(\phi,\eta,t)$. We have:

$$\frac{\mathrm{d}^2\hat{\pi}^d}{\mathrm{d}t\mathrm{d}\phi} = \frac{b_n^{3/2}\left(\hat{\pi}^d\right)^{1/2}\left\{2\eta+\left[\left(\mathrm{d}\hat{\pi}^d/\mathrm{d}\phi\right)\left(\hat{\pi}^d\right)^{-1}+\eta(1-\phi\eta)^{-1}\right](1+\phi\eta)\right\}}{\left(4b_n^2-1\right)(1-\phi\eta)^{1/2}} > 0$$

The previous expression is positive because, from Assumption 2.5, we have: $\mathrm{d}\hat{\pi}^d/\mathrm{d}\phi > 0$. The other terms are positive. Therefore, the vertical differentiation increases the positive impact of the tariff on the Northern firm's profit. It can be deduced then, that the difference in profit increases with the tariff as compared to free trade. The Northern firm's R&D expenditures also increase. □

The tariff leads to a gain for the Northern firm. It is encouraged to invest more in order to benefit from a stronger gain. This can be explained by the drop in the intensity of competition from the Southern country. Since the tariff reduces imports from the low-cost country, the Northern firm is encouraged to increase its R&D investment in order to increase the probability of vertical differentiation and further reduce its competitor's exports. As a result, the cost of the tariff on the Southern firm's profit is greater in case of a successful R&D, because the effect is all the more negative on its market share.

Nevertheless, we cannot demonstrate that these results hold under general forms for demand functions. The effect of the tariff on the difference in profit is always positive under any other linear form for demand functions. But under nonlinear forms, we cannot prove that the result is always positive (see Appendix 2.A).

2.4.2. A Production Subsidy

Consider now that the Northern government decides to subsidize the Northern firm's output (both domestic sales and exports). The Northern firm's profit expression changes compared to free trade:

$$\pi = \begin{cases} \pi^h = p_n^h x_n^h + p_s^h x_s^h - \left(c^h + s\right)\left(x_n^h + x_s^h\right) - g x_s^h, \text{ if } \phi = 0 \\ \pi^d = p_n^d x_n^d + p_s^d x_s^d - \left(c^d + s\right)\left(x_n^d + x_s^d\right) - g x_s^d, \text{ otherwise.} \end{cases} \tag{2.14}$$

In contrast to the specific tariff, the implementation of a production subsidy has repercussions on both the Northern and Southern markets. Its economic impact is the same as that of a decrease of the marginal cost for the Northern firm. This results in a drop in prices on both markets. While, the impact of the subsidy on the Northern firm's output and profit is positive, its Southern competitor's domestic sales, exports and profit decrease. Nevertheless, the overall sales on the Northern and Southern markets both increase. There is a direct positive impact on the Northern country's consumer surplus.

Proposition 2.2: The Northern firm's R&D investment increases if the following condition were verified: $(1-\phi\eta)\left(\mathrm{d}\hat{\pi}_i^d/\mathrm{d}\phi\right) > \eta\hat{\pi}_i^d$. It decreases, otherwise. Using numerical simulations, we only find cases in which the effect is positive.

Proof: □ Since the derivative of a sum is the sum of the derivatives, we have:

$$\frac{\mathrm{d}^2\hat{\pi}^d(\phi,\eta,s)}{\mathrm{d}s\mathrm{d}\phi} = \frac{\mathrm{d}^2\hat{\pi}_n^d(\phi,\eta,s)}{\mathrm{d}s\mathrm{d}\phi} + \frac{\mathrm{d}^2\hat{\pi}_s^d(\phi,\eta,s)}{\mathrm{d}s\mathrm{d}\phi}$$

We denote by $\pi_i, \forall i = \{n, s\}$ the Northern firm's profit share earned on the market i. Setting $\hat{\pi}_i^d = \hat{\pi}_i^d(\phi,\eta,s)$ to simplify expressions, we have:

$$\frac{\mathrm{d}^2\hat{\pi}_i^d}{\mathrm{d}s\mathrm{d}\phi} = \frac{b_i^{3/2}(2b_i^2-1)\hat{\pi}_i^{d^{1/2}}\left[(1-\phi\eta)(d\hat{\pi}_i^d/d\phi)\hat{\pi}_i^{d^{-1}}-\eta\right]}{(4b_i^2-1)(1-\phi\eta)^{1/2}}$$

The sign of the term in brackets is undetermined. Therefore, we cannot demonstrate that the impact is always positive. The expression above would be positive if the following condition were verified: $(1-\phi\eta)\left(\mathrm{d}\hat{\pi}_i^d/\mathrm{d}\phi\right) > \eta\hat{\pi}_i^d$. □

We offer the following economic explanation to this inconclusive mathematical result. Following the implementation of the production subsidy by the Northern government, both markets experience a fall in prices. The magnitude of the effect is however, greater for the Northern firm. As a result, its domestic sales and exports increase. The increase is even bigger compared to a tariff. As stated previously, the main feature of vertical differentiation is the change in demand functions. In case of a production subsidy, the increase of demand for the Northern firm's good is such as the Northern firm may be less encouraged to increase its R&D investment.

Nevertheless, taking numerical values for parameters, we always find a positive impact of the production subsidy on the difference in profit. The Northern firm is generally encouraged to increase its R&D investment because the revenues of the subsidy increase with the level of output. Such a level increases with vertical differentiation. The effect of the production subsidy on the R&D investment is positive in this case, because the output effect is stronger than the price effect.

2.4.3. An R&D Subsidy

Consider now the case in which the Northern government subsidizes its domestic firm's R&D investment. Such a specific subsidy reduces the total R&D cost. The Northern firm's expected profit changes compared to free trade:

$$E[\Pi(r,\sigma)] = \alpha(r)\hat{\pi}^d + [1-\alpha(r)]\hat{\pi}^h - (v-\sigma)r \tag{2.15}$$

The optimal R&D investment is now:

$$r(\sigma) = \left[\frac{k(\hat{\pi}^d - \hat{\pi}^h)}{v - \sigma}\right]^{\frac{1}{1-k}} \tag{2.16}$$

The R&D subsidy does not directly influence prices and outputs. But there is an indirect impact by influencing the Northern firm's R&D expenditures and the probability of R&D success.

Proposition 2.3: The Northern firm's R&D investment increases with its government's R&D subsidy as compared to the initial situation without subsidy.

Proof: □ The subsidy σ reduces the denominator of $r(\sigma)$. Therefore, the R&D investment increases with the R&D subsidy: $\mathrm{d}r(\sigma)/\mathrm{d}\sigma > 0$. The Northern firm increases its R&D investment because the total R&D cost is lower. □

2.4.4. A Quality Standard

The Northern government may decide to implement a quality standard on the domestic market regardless of the outcome of the R&D. In this case, the introduction of a quality standard gives the Northern firm a monopoly power on the Northern market if the R&D is successful, since its competitor produces a lower quality good and does not meet the standard. Therefore, the demand for the Northern firm's product no longer depends on the Southern firm's price. But if the R&D is unsuccessful, there is no market in the Northern country.

We use the superscripts hs and ds for variables with the quality standard. Under the successful case, we set $y_n^{ds} = 0$ in order to express p_n^{*d} as a function of p_n^d. We deduce the following demand function for the Northern firm's product sold on its domestic market:

$$x_n^{ds}\left(p_n^{ds}, \phi\eta\right) = \{a_n[b_n(1 + \phi\eta) + 1 - \phi\eta] - (b_n^2 - 1)(1 - \phi\eta)p_n^{ds}\}/b \tag{2.17}$$

Prices and demand functions on the Southern market are unchanged. For example, x_s^d still denotes the Northern firm's exports. The profit expressions are:

$$\pi = \begin{cases} \pi^{hs} = p_s^h x_s^h - \left(c^h + g\right)x_s^h, \text{ if } \phi = 0 \\ \pi^{ds} = p_n^{ds}x_n^{ds} + p_s^d x_s^d - c^d\left(x_n^{ds} + x_s^d\right) - g x_s^d, \text{ otherwise.} \end{cases} \tag{2.18}$$

$$\pi^* = \begin{cases} \pi^{*dh} = p_s^{*h} y_s^h - c^* y_s^h, \text{ if } \phi = 0 \\ \pi^{*ds} = p_s^{*d} y_s^d - c^* y_s^d, \text{ otherwise.} \end{cases} \tag{2.19}$$

With a successful R&D, the Northern firm's equilibrium price of domestic sales is:

$$\hat{p}_n^{ds}(\phi, \eta) = \frac{a_n(b_n+1) + (b_n^2-1)c^d(\phi) + \phi\eta\left[a_n(b_n-1) - (b_n^2-1)c^d(\phi)\right]}{2(b_n^2-1)(1-\phi\eta)} \tag{2.20}$$

Since there is no longer competition from the Southern firm, the Northern firm's price on its domestic market increases as compared to free trade in case of a successful R&D investment. The monopoly situation relates to a case in which the Southern firm sets a level of price of exports approaching infinity because the demand for its product would tend toward zero in this case. According to the reaction functions under the initial case without quality standard, the Northern firm's domestic price increases with the Southern firm's foreign price: $\mathrm{d}p_n^d/\mathrm{d}p_n^{*d} = (1+\phi\eta)/[2b_n(1-\phi\eta)] > 0$. This result entails that the Northern firm's domestic price is higher as compared to the initial case.

The Northern firm's domestic sales are:

$$\hat{x}_n^{ds}(\phi,\eta) = \frac{a_n(b_n+1)-(b_n^2-1)c^d(\phi)+\phi\eta[a_n(b_n-1)+(b_n^2-1)c^d(\phi)]}{2b_n} \tag{2.21}$$

The Northern firm’s domestic sales also increase when a quality standard is implemented. By the same reasoning as above we have: $\mathrm{d}x_n^d/\mathrm{d}p_n^{*d} = (\partial x_n^d/\partial p_n^d)(\mathrm{d}p_n^d/\mathrm{d}p_n^{*d}) + \partial x_n^d/\partial p_n^{*d} = (1+\phi\eta)/2 > 0$. However, total sales on the Northern market decrease because the Southern firm leaves the market and the domestic price increases.

Finally, the Northern firm’s profit earned on its domestic market equals:

$$\hat{\pi}_n^{ds}(\phi,\eta) = \frac{a_n(b_n+1)-(b_n^2-1)c^d(\phi)+\phi\eta[a(b_n-1)+(b_n^2-1)c^d(\phi)]}{4b_n(b_n^2-1)(1-\phi\eta)} \tag{2.22}$$

Given the monopoly situation, the Northern firm's optimal level of profit is greater than the free trade level. Moreover, the Northern firm sets a higher price and its marginal profit increases. Its level of output is also stronger.

We now look for the impact of the quality standard on the Northern firm’s R&D investment. The equilibrium level of R&D is given by:

$$r = \left[\frac{k(\hat{\pi}^{ds}-\hat{\pi}^{hs})}{v}\right]^{\frac{1}{1-k}} \tag{2.23}$$

Proposition 2.4: The Northern firm’s R&D investment increases with the implementation of the quality standard.

Proof: □ The quality standard only increases the Northern firm’s profit if the R&D is successful. With an unsuccessful R&D, such a profit decreases because there is no market in the North while the profit earned in the South is the same as compared to the initial case. Therefore, the difference in profit increases as compared to the initial case: $(\hat{\pi}^{ds}-\hat{\pi}^{hs}) > (\hat{\pi}^{d}-\hat{\pi}^{h})$. The Northern firm increases its R&D investment in order to increase the probability of R&D success, and then, to benefit from the monopoly in the North with the quality standard. □

2.4.5. A Minimum price

The quality standard is a prohibitive quota in case of a successful R&D. The Northern government may also implement price restrictions. Consider a minimum price such as the Southern firm cannot sell its product on the Northern market with a lower price. The Southern firm's profit expression is:

$$\pi^* = \begin{cases} \pi^{*h} = p_{min} y_n^h + p_s^{*h} y_s^h - c^*\left(y_n^h + y_s^h\right) - g^* y_n^h, \text{if } \phi = 0 \\ \pi^{*d} = p_{min} y_n^d + p_s^{*d} y_s^d - c^*\left(y_n^d + y_s^d\right) - g^* y_n^d, \text{otherwise.} \end{cases} \tag{2.24}$$

The Northern government can select two levels of minimum price:

- A relatively binding minimum price such as: $\hat{p}_n^{*d} < p_{min} \leq \hat{p}_n^{*h}$. The minimum price has only an economic impact if the R&D is successful. There is no effect when the R&D is unsuccessful.
- A strongly binding minimum price such as: $p_{min} > \hat{p}_n^{*h}$. The minimum price has an impact whatever the R&D outcome.

Note that there is a third case in which the minimum price is not binding: $p_{min} \leq \hat{p}_n^{*d}$. We do not study this case because the effect of the minimum price would be null. Only the Northern firm selects the optimal level of price that maximizes its profit. Under a successful R&D, we have:

$$\hat{p}_n(\phi, \eta, p_{min}) = \frac{a_n + b_n c^d(\phi) + p_{min} + \phi\eta[a_n - b_n c^d(\phi) + p_{min}]}{2b_n(1-\phi\eta)} \tag{2.25}$$

The Northern firm's domestic sales and the Southern firm's exports are respectively:

$$\hat{x}_n(\phi, \eta, p_{min}) = \frac{a_n - b_n c^d(\phi) + p_{min} + \phi\eta[a_n + b_n c^d(\phi) + p_{min}]}{2};$$

$$\hat{y}_n(\phi, \eta, p_{min}) = \frac{a_n(2b_n+1) + b_n c^d(\phi) - p_{min}(2b_n^2-1) - \phi\eta[a_n(2b_n-1) + b_n c^d(\phi) + p_{min}(2b_n^2-1)]}{2b_n} \tag{2.26}$$

The Northern firm's domestic price increases as compared to free trade because prices are strategic complements under Bertrand competition. Meanwhile, the Southern firm's exports decrease with the minimum price because its price of exports is higher as compared to a free trade. Conversely, the effect on the Northern firm's output is positive even if its price also increases. The minimum price increases the Northern firm's market share.

The equilibrium profit shares earned on the Northern market are:

$$\hat{\pi}_n^d(\phi, \eta, p_{min}) = \frac{\{a_n - b_n c^d(\phi) + p_{min} + \phi\eta[a_n + b_n c^d(\phi) + p_{min}]\}^2}{4b_n(1-\phi\eta)};$$

$$\hat{\pi}_n^{*d}(\phi, \eta, p_{min}) = \frac{\{a_n(2b_n+1) + b_n c^d(\phi) - p_{min}(2b_n^2-1) - \phi\eta[a_n(2b_n-1) + b_n c^d(\phi) + p_{min}(2b_n^2-1)]\}(p_{min} - c^*)}{2b_n} \tag{2.27}$$

The Northern firm's profit increases with the minimum price. The impact is also positive in case of an unsuccessful R&D. The Southern firm cannot maximize its profit anymore on the Northern market. Therefore, its profit decreases.

Proposition 2.5: The Northern firm's R&D investment increases with both a relatively and a strongly binding minimum price.

Proof: □ We consider two cases:

- First, let us study the impact of the relatively binding minimum price. In case of an unsuccessful R&D investment, the Northern firm's profit is the same as under free trade. This profit increases as compared to free trade with a successful R&D. The difference in profit increases with the relatively binding minimum price.
- Now, let us study the impact of the strongly binding minimum price. The Northern firm's profit increases as compared to free trade whatever the R&D outcome. Since a relatively binding minimum price increases the difference in profit, we have to find the second derivative of the Northern firm's profit with respect to the minimum price and to the degree of differentiation. Setting $\hat{\pi}_n^d = \hat{\pi}_n^d(\phi, \eta, p_{min})$ to simplify expressions, we have:
  $$\frac{\mathrm{d}^2\hat{\pi}_n^d}{\mathrm{d}p_{min}\mathrm{d}\phi} = \frac{{\hat{\pi}_n^d}^{1/2}\left\{2\eta+(1+\phi\eta)\left(\mathrm{d}\hat{\pi}_n^d/\mathrm{d}\phi\right){\hat{\pi}_n^d}^{-1}+\eta(1+\phi\eta)(1-\phi\eta)^{-1}\right\}}{[4b_n(1-\phi\eta)]^{1/2}} > 0$$
  The positive impact of p_{min} on $\hat{\pi}_n^d$ increases with ϕ. The difference in profit also increases with the strongly binding minimum price.

Therefore, the Northern firm's R&D investment increases with the minimum price as compared to free trade. The impact is positive with both the relatively and strongly binding minimum price. □

2.4.6. An Import Quota

Let us study the impact of an import quota implemented by the Northern government. We have analyzed the impact of a quality standard i.e. a specific prohibitive quota. But governments can also implement traditional quotas. Under free trade, when the R&D is successful, we can express the Southern firm's price of exports as a function of the Northern firm's price of domestic sales and of the Southern firm's exports: $p_n^{*d} = \left[\left(a_n + p_n^d\right)(1-\phi\eta) - y_n^d\right]/[b_n(1+\phi\eta)]$. With a binding quota, we have:

$$p_n^{*d}\left(p_n^d, \phi\eta, q\right) = [(a_n + p_n^*)(1-\phi\eta) - q]/[b_n(1+\phi\eta)] \tag{2.28}$$

Such an expression is the Southern firm's best-response to the Northern firm's price of domestic sales. It also depends on the level of the quota, since the quota is binding. The Southern firm no longer maximizes its profit with respect to its price of exports. It only reacts to the levels of p_n^d and q.

Integrating the expression of p_n^{*d} in x_n^d, we have:

$$x_n^d\left(p_n^d, \phi\eta, q\right) = \{a_n[b_n(1+\phi\eta) + 1 - \phi\eta] - (1-\phi\eta)(b_n^2 - 1)p_n^d - q\}/b_n \tag{2.29}$$

The demand for the Northern firm's good on the Northern market no longer depends on the level of the Southern firm's price of exports because such a price is a response to the Northern firm's price of domestic sales and to the level of the quota.

The Southern firm's profit expression is now:

$$\pi^* = \begin{cases} \pi^{*h} = qp_n^{*h} + p_s^{*h} y_s^h - c^*\left(q + y_s^h\right) - g^* q, \text{if } \phi = 0 \\ \pi^{*d} = qp_n^d + p_s^{*d} y_s^d - c^*\left(q + y_s^d\right) - g^* q, \text{otherwise.} \end{cases} \quad (2.30)$$

The quota does not influence the outcome on the Southern market. On the Northern market, the Northern firm selects the optimal price of domestic sales:

$$\hat{p}_n^d(\phi, \eta, q) = \frac{a_n(b_n+1) + c^d(\phi)\left(b_n^2-1\right) - q + \phi\eta\left[a_n(b_n-1) - c^d(\phi)\left(b_n^2-1\right)\right]}{2\left(b_n^2-1\right)(1-\phi\eta)} \quad (2.31)$$

The Northern firm's price of domestic sales increases with a binding quota as compared to free trade owing to the drop in the competition from the Southern country.

The Southern firm's best-response is:

$$\hat{p}_n^{*d}(\phi, \eta, q) = \frac{a_n\left(2b_n^2+b_n-1\right) - q\left(2b_n^2-1\right) - \phi\eta\left[a_n\left(2b_n^2-b_n-1\right) + c^d(\phi)\left(b_n^2-1\right)\right]}{2b_n\left(b_n^2-1\right)(1+\phi\eta)} \quad (2.32)$$

The Southern firm's price of exports also increases with a binding quota as compared to free trade.

The Northern firm's domestic sales equal:

$$\hat{x}_n^d(\phi, \eta, q) = \frac{a_n(b_n+1) - c^d(\phi)\left(b_n^2-1\right) - q + \phi\eta\left[a_n(b_n-1) + c^d(\phi)\left(b_n^2-1\right)\right]}{2b_n} \quad (2.33)$$

The Northern firm's domestic sales increase with a binding quota as compared to free trade.

Finally, the equilibrium profits on the Northern market are:

$$\hat{\pi}_n^d(\phi, \eta, q) = \frac{\left\{a_n(b_n+1) - c^d(\phi)\left(b_n^2-1\right) - q + \phi\eta\left[a_n(b_n-1) + c^d(\phi)\left(b_n^2-1\right)\right]\right\}^2}{4b_n\left(b_n^2-1\right)(1-\phi\eta)};$$

$$\hat{\pi}_n^{*d}(\phi, \eta, q) = \frac{q\left\{a_n\left(2b_n^2+b_n-1\right) - 2b_n\left(b_n^2-1\right)(c^*+g^*) - q\left(2b_n^2-1\right) - \phi\eta\left[a_n\left(2b_n^2-b_n-1\right) + c^d(\phi)\left(b_n^2-1\right) + 2b_n\left(b_n^2-1\right)(c^*+g^*)\right]\right\}}{2b_n\left(b_n^2-1\right)(1+\phi\eta)} \quad (2.34)$$

The Northern firm's profit increases with a binding quota as compared to free trade. The Southern firm's profit decreases because it no longer sets the optimal level of price of exports that maximizes its profit. It only sets the best response to q and p_n^d.

We consider two cases:

- First case: $\hat{y}_n^d(\phi, \eta) \leq q < \hat{y}_n^h$. The quota is relatively binding because it only reduces the Southern firm's exports when the R&D is unsuccessful. The Northern firm's profit only increases as compared to free trade under this case: $\hat{\pi}_n^h(q) > \hat{\pi}_n^h, \hat{\pi}_n^d(q) = \hat{\pi}_n^d$.
- Second case: $q < \hat{y}_n^d(\phi, \eta)$. The quota is strongly binding because it reduces the Southern firm's exports under both cases. The Northern firm's profit increases as compared to free trade regardless of the R&D outcome: $\hat{\pi}_n^h(q) > \hat{\pi}_n^h, \hat{\pi}_n^d(q) > \hat{\pi}_n^d$.

Proposition 2.6: The Northern firm's R&D investment decreases with a relatively binding quota and either increases or decreases with a strongly binding quota as compared to free trade. There is a non-null value of quota $\overline{q}$ such as the R&D investment equals the free trade level. Therefore, the Northern firm's R&D investment decreases as compared to free trade when $q \in (\overline{q}, \hat{y}_n^d)$, levels off when $q = \overline{q}$, and increases when $q \in [0, \overline{q})$.

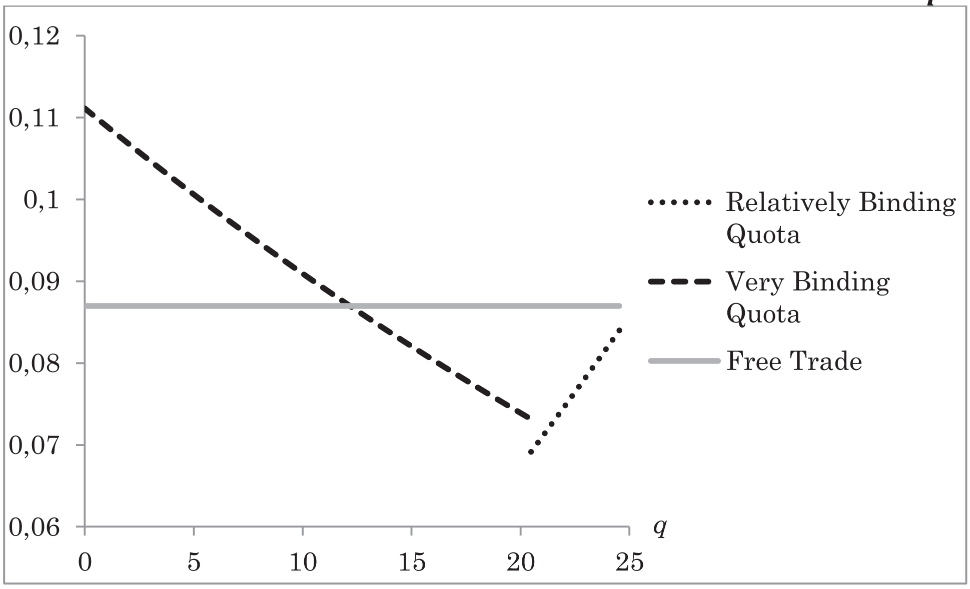
Proof: □ Let us consider the two cases:

- With a relatively binding quota, the quota is only binding when the R&D is unsuccessful. The Northern firm's profit only increases under this case. The difference in profit decreases as compared to free trade: $\hat{\pi}_n^d(\phi, \eta, q) - \hat{\pi}_n^h(q) < \hat{\pi}_n^d(\phi, \eta) - \hat{\pi}_n^h$.
- With a strongly binding quota, the quota is binding under both cases. The Northern firm's profit increases regardless of the R&D outcome. We have:
  $\frac{\mathrm{d}\hat{\pi}_n^d(\phi,\eta,q)}{\mathrm{d}q} = -\frac{2\hat{x}_n^d(\phi,\eta,q)}{2(b_n^2-1)(1-\phi\eta)} < 0$
  The positive effect of a drop in q on π equals $2\hat{x}_n^d(\phi, \eta, q)/[2(b_n^2 - 1)(1 - \phi\eta)]$. Such an expression increases with ϕ because $\mathrm{d}\hat{x}_n^d(\phi, \eta, q)/\mathrm{d}\phi > 0$. The positive effect of the quota on the Northern firm's profit is greater when the R&D is successful. The difference in profit increases when the level of the quota decreases. But, since a relatively binding quota reduces the R&D, such a result is not sufficient to prove that the difference in profit always increases as compared to free trade. We denote by $\overline{q}$ the quota such as the difference in profit equals the free trade level. The difference in profit decreases with a strongly binding quota q such as $q \in (\overline{q}, \hat{y}_n^d)$ if $0 < \overline{q} < \hat{y}_n^d$. The difference in profit also always decreases with a strongly binding quota if $\overline{q} = 0$. It always increases, otherwise.

The Northern firm's R&D investment decreases with a relatively binding quota, and either increases or decreases with a strongly binding quota. Let us use a numerical example. Figure 2.2 illustrates the evolution of the Northern firm's R&D investment when the level of the quota varies. The grey line illustrates the free trade level. Here, we find $\overline{q} \approx 12.1738$, with $0 < \overline{q} < \hat{y}_n^d$. Under such a numerical example, the R&D investment decreases with a strongly binding quota as compared to free trade if $q \in (\overline{q}, \hat{y}_n^d)$. It levels off if $q = \overline{q}$. It increases if $q \in [0, \overline{q})$. We have already explained these specific results in Chapter 1, Section 1.3.5. □

-Figure 2.2-

Evolution of the Northern firm's Product R&D Investment When q Varies



Source: authors.
Note: $c^d(\phi) = c^h + \phi; \alpha(r) = r^k; a_n = 40; a_s = 30; b_n = b_s = 2; c^h = 6; c^* = 3; g = g^* = 1; \phi = 0.2; \eta = 1; v = 500; k = 0.5; F = F^* = 0$.

2.5. Welfare Analysis

We have examined the impact of six policy instruments on the Northern firm's R&D investment. Let us study the economic impact of each instrument by analyzing their impact on expected profits, consumer surplus and public revenues.

2.5.1. General Framework under Free Trade

Each expected variable depends on the equilibrium expression of the R&D investment $\hat{r}$. The expected profit expressions are:

$$E\left[\widehat{\Pi}(\hat{r})\right] = \alpha(\hat{r})\hat{\pi}^d + [1 - \alpha(\hat{r})]\hat{\pi}^h - vr; E\left[\widehat{\Pi}^*(\hat{r})\right] = \alpha(\hat{r})\hat{\pi}^{*d} + [1 - \alpha(\hat{r})]\hat{\pi}^{*h}$$

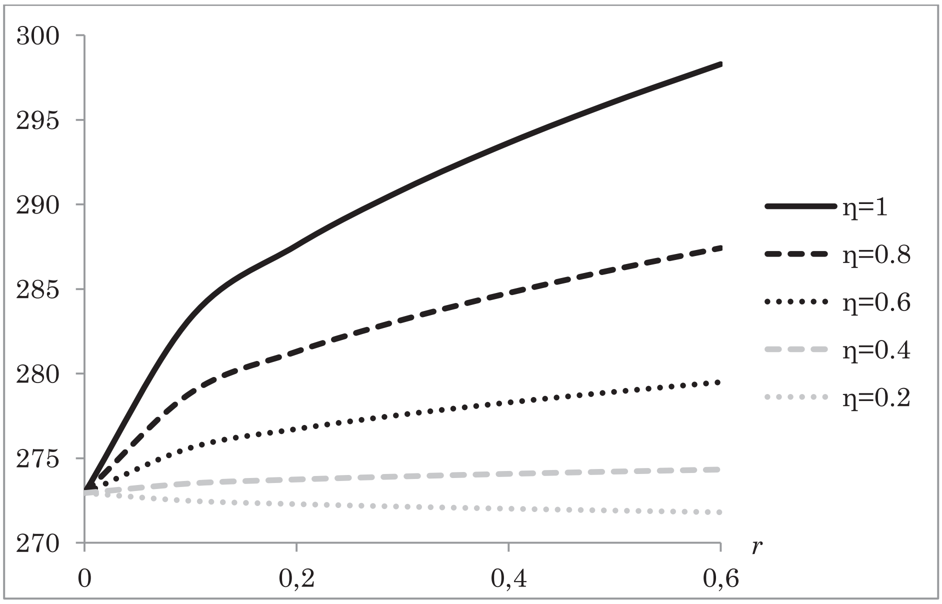
Let us study each country's expected consumer surplus. We need to express the domestic (foreign) price as a function of the domestic (foreign) sales by turning the domestic (foreign) demand function and considering the foreign (domestic) price as a parameter. We have:

$$E\left[\widehat{\mathrm{CS}}(\hat{r})\right] = \alpha(\hat{r})\left[\int_0^{\hat{x}_n^d} p_n^d(x_n^d)\mathrm{d}x_n^d - p_n^d(\hat{x}_n^d)\hat{x}_n^d + \int_0^{\hat{y}_n^d} p_n^{*d}(y_n^d)\mathrm{d}y_n^d - p_n^{*d}(\hat{y}_n^d)\hat{y}_n^d\right] + [1 - \alpha(\hat{r})]\left[\int_0^{\hat{x}_n^h} p_n^h(x_n^h)\mathrm{d}x_n^h - p_n^h(\hat{x}_n^h)\hat{x}_n^h + \int_0^{\hat{y}_n^h} p_n^{*h}(y_n^h)\mathrm{d}y_n^h - p_n^{*h}(\hat{y}_n^h)\hat{y}_n^h\right]$$

$$E\left[\widehat{\mathrm{CS}}^*(\hat{r})\right] = \alpha(\hat{r})\left[\int_0^{\hat{x}_s^d} p_s^d(x_s^d)\mathrm{d}x_s^d - p_s^d(\hat{x}_s^d)\hat{x}_s^d + \int_0^{\hat{y}_s^d} p_s^{*d}(y_s^d)\mathrm{d}y_s^d - p_s^{*d}(\hat{y}_s^d)\hat{y}_s^d\right] + [1 - \alpha(\hat{r})]\left[\int_0^{\hat{x}_s^h} p_s^h(x_s^h)\mathrm{d}x_s^h - p_s^h(\hat{x}_s^h)\hat{x}_s^h + \int_0^{\hat{y}_s^h} p_s^{*h}(y_s^h)\mathrm{d}y_s^h - p_s^{*h}(\hat{y}_s^h)\hat{y}_s^h\right]$$

-Figure 2.3-

Evolution of the Expected Northern Consumer Surplus When the R&D Investment Varies



Source: authors.
Note: We set: $c^d(\phi) = c^h + \phi; a_n = 40; a_s = 30; b_n = b_s = 2; c^h = 6; c^* = 3; g = g^* = 1; \phi = 0.2; F = F^* = 0.$

We can study the impact of the R&D investment on the Northern country's consumer surplus. As illustrated in Figure 2.3, the impact is negative for a low sensitivity η of consumers' preference for quality improvement (for example, if $\eta = 0.2$). The lower η, the lower the consumers' preference for quality. Since vertical differentiation increases the Northern firm's price, the effect on the consumer surplus is then negative. The impact is positive, otherwise. The effect on the Southern country's expected consumer surplus is symmetric.

Under free trade, the Northern country's expected national welfare equals the sum of its expected profit and domestic consumer surplus: $E[\widehat{\mathrm{W}}(\hat{r})] = E[\widehat{\Pi}(\hat{r})] + E[\widehat{\mathrm{CS}}(\hat{r})]$. Same goes for the Southern country's expected welfare: $E[\widehat{\mathrm{W}}^*(\hat{r})] = E[\widehat{\Pi}^*(\hat{r})] + E[\widehat{\mathrm{CS}}^*(\hat{r})]$.

2.5.2. Discussion

Table 2.1 illustrates the economic impact of each policy instrument. We also study the impact on the Northern country's expected public revenues.

-Table 2.1-

Economic Impact of Each Policy Instrument

Instrument	r	$E(\Pi)$	$E(\Pi^*)$	$E(\mathrm{CS})$	$E(\mathrm{CS}^*)$	$E(\mathrm{PR})$
Import Tariff	+	+	–	+/–	+/–	+
Production Subsidy	+	+	–	+	+	–
R&D Subsidy	+	+	–	+/–	+/–	–
Quality Standard	+	+/–	–	+/–	+/–	0
Minimum price	+	+	–	+/–	+/–	0
Import Quota	+/–	+/–	+/–	+/–	+/–	0

Source: authors.

Each policy instrument increases the Northern firm's R&D expenditures except for the quality standard and the import quota. A government that aims to enhance non-price competitiveness by encouraging product R&D investment should implement one of these policy instruments. Furthermore, the Northern (Southern) firm's expected profit always increases (decreases) with each policy instrument. This result relates to the "profit-shifting" mentioned in the economic literature. Nevertheless, policy instruments may have opposite impacts on expected consumer surplus and public revenues. The Northern country's expected public revenues increase with the import tariff, decrease with the production subsidy and the R&D subsidy, and level off with the quality standard and the minimum price.

Let us study the impact on the Northern country's consumer surplus. It increases with the production subsidy because it has a direct impact by reducing the levels of price. The R&D subsidy has an indirect impact by increasing the probability of R&D success. But the impact on the expected consumer surplus may be negative if the sensitivity η is low. The impact of the import tariff and the minimum price may be either positive or negative because of a direct negative impact due to the increase of levels of price and an indirect positive impact due to the increase of the probability of R&D success. The impact of each policy instrument on the Southern country's consumer surplus is the same.

The economic impact of the quality standard is uncertain. The effect on the Northern firm's expected profit is unknown because the effect is positive with a successful R&D and negative with an unsuccessful R&D. The effect on the Northern consumer surplus is uncertain because it increases the Northern firm's R&D investment but it reduces the total demand on the Northern market. The economic impact of a quota is also ambiguous because it reduces the competition from the Southern country but it either increases or reduces the Northern firm's R&D investment. Therefore, the effect on each expected profit and consumers' surplus is uncertain.

Appendix 2.B illustrates the evolution of the Northern country's expected consumer surplus when the Northern government implements: (i) an import tariff such as $t = 1$; (ii) a quality standard; (iii) a relatively binding minimum price such as $p_{min} = p^{*d} + z$, where z is a positive constant; (iv) a strongly binding minimum price such as $p_{min} = p^{*h} + z$; (v) a prohibitive import quota.

The effect of the tariff is often negative. Nevertheless, we find a case in which the expected consumer surplus increases with the tariff. The effect is positive for $\eta \geq 2.3$ when $b = 3$. We also find a case in which the quality standard increases the expected consumer surplus for $\eta \geq 1.25$ when $b = 3$. Finally, the relatively binding minimum price increases the expected consumer surplus for $\eta \geq 1.5$ when $b = 2$, and for $\eta \geq 1.75$ when $b = 3$, while the strongly binding minimum price increases it for $\eta \geq 1.25$ when $b = 2$.

Under these cases, the indirect positive impact via the probability of R&D success is stronger than the direct negative impact via the increase in prices. Such a result can be offset against traditional results that mention a negative impact of "at-the-border" policy instruments on the consumer surplus. The condition is that consumers have a high sensitivity on their preference for quality.

Unlike an import tariff and a quality standard, we do not find any case in which a strongly binding quota increases the Northern country's expected consumer surplus by using numerical simulations.

2.5.3. Optimal Policy Instruments under Numerical Simulations

According to the economic impact of each policy instrument, we have to verify whether or not the Northern government is encouraged to implement it. Let us study the impact on each country's expected national welfare. We can also compare each instrument. Appendix 2.C illustrates the optimal level of each instrument and the expected national welfare as compared to free trade. The results are obtained under numerical simulations because analytical demonstrations seem complex.

- The Northern country's national welfare is always increased with the implementation of an import tariff and a production subsidy. The tariff is the favorite policy instrument because: (i) it increases the Northern firm's profit through the profit-shifting; (ii) it also increases its R&D investment; (iii) it involves further public revenues for the government; (iv) it may increase the expected consumer surplus when their preference for quality is high (the negative effect is low, otherwise).
- The positive impact of the production subsidy is lower even if it is the favorite policy instrument for the Northern consumer since it reduces prices and increases the probability of vertical differentiation. The reason is that it involves public expenditures, especially if the R&D is successful.
- The quality standard reduces the Northern country's expected national welfare under each case illustrated in Appendix 2.B. The effect may be positive with higher values for η. But the quality standard is never the Northern government's favorite policy instrument. The Northern government has a preference for the import tariff because we consider that the quality standard does not yield public revenues. Furthermore, the effect on the domestic consumer surplus is often negative. The quality standard is the most binding policy instrument. It is a prohibitive quota not only for the Southern firm but also for the Northern firm if the R&D is unsuccessful.
- Under four cases, the Northern country's national welfare is not increased with the minimum price because the optimal level equals the free trade level of price when the R&D is successful. Therefore, the expected Northern welfare is the same as under free trade. This welfare increases with the minimum price, otherwise. The main difference with the import tariff is that we do not consider that the minimum price influences public revenues.
- Under two cases, the optimal R&D subsidy is negative. Therefore, the Northern government is encouraged to tax the Northern firm's R&D expenditure. Note that the effects on the expected welfare are low because it only directly impacts the probability of R&D success.
- The quota increases the Northern country's expected national welfare under seven cases. In these cases, the optimal quota is a prohibitive quota such as the Northern firm benefits from a monopoly on its domestic market. But the quota reduces the

expected national welfare under five cases. In these cases, the Northern government remains under free trade.

- Each policy instrument reduces the Southern country's expected national welfare except for negative R&D subsidies i.e. R&D taxes because they increase the Southern firm's profit.

The results show that the import tariff seems to be the favorite policy instrument for the Northern government. The Northern government can increase its domestic firm's expected profit, its consumer surplus and public revenues at the same time, only by implementing an import tariff. However, there is a limit. Tariffs represent traditional forms of trade policy. Currently, governments reduce their tariff rates by implementing free trade agreements and use modern forms of protectionism like subsidies, quality standards and minimum prices. Furthermore, according to the WTO, tariffs are bound and cannot be increased above a certain level. Nevertheless, the level of European Union's ad-valorem import tariff is high in the automobile industry. It may legitimize our results.

2.6. Concluding Remarks

In this chapter, we have designed a theoretical model of international trade in a two-country duopoly with a Northern and Southern firm to study the impact of several trade policy instruments on product R&D investment and national welfares. The Southern firm is considered to have a competitive advantage due to lower production costs, encouraging the Northern competitor to invest in quality improvement. The Northern government is the only one policy active, having the choice between several policy instruments: an import tariff, a production subsidy, an R&D subsidy, a quality standard, a minimum price and an import quota. Firms compete in prices on both markets.

Through our three-stage game, we show that each policy instrument increases the Northern firm's product R&D investment except for an import quota. Therefore, if the Northern government's only aim is to enhance non-price competitiveness by encouraging product R&D investment, we provide evidence in favor of implementing these policy instruments. However, it is also argued that the effect of some of these instruments may hinder consumer surplus, public revenues and welfare. Their implementation might not therefore be socially optimal. This result is backed by numerical simulations allowing for a change in the levels of parameters. Based on these simulations and a comparison of the impact of these instruments, it appears that the Northern government would favor the implementation of an import tariff. By this means, the domestic expected profit, consumer surplus and public revenues could increase. The real implications of this result are limited, as the ongoing trend in the international arena is towards the reduction of this trade barrier.

The possible positive effect of the import tariff on the consumer surplus is an original result in this chapter. The reason is that the tariff increases the Northern firm's R&D and the probability of R&D success. If the consumer's sensitivity on their preference for quality is high, such a positive effect may be greater than the negative effect of the increase in prices.

Appendix to Chapter 2

2.A. Impact of an Import Tariff under General Forms for Demand Functions

We use general forms for demand functions. Nevertheless, we still consider constant marginal costs and linear forms for total costs. According to the first order conditions, we have: $\hat{\pi}_n^h(t) = \pi_n^h[\hat{p}_n^h(t)] = -x_{n_{p_n}}^h[\hat{p}_n^h(t) - c^h]^2, \hat{\pi}_n^d(t) = \pi_n^d[\hat{p}_n^d(t)] = -x_{n_{p_n}}^h[\hat{p}_n^d(t) - c^d(\phi)]^2$. Subscripts denote partial derivatives. We have:

$$\frac{\mathrm{d}\hat{\pi}_n^h(t)}{\mathrm{d}t} = \frac{\partial \pi_n^h[\hat{p}_n^h(t)]}{\partial t} + \frac{\partial \pi_n^h[\hat{p}_n^h(t)]}{\partial \hat{p}_n^h(t)} \frac{\mathrm{d}\hat{p}_n^h(t)}{\mathrm{d}t} = [\hat{p}_n^h(t) - c^h] \frac{y_{n\,p_n^*}^h \pi_{n\,p_n p_n}^h \pi_{n\,p_n p_n^*}^h}{B^h} > 0$$

$$\frac{\mathrm{d}\hat{\pi}_n^d(t)}{\mathrm{d}t} = \frac{\partial \pi_n^d[\hat{p}_n^d(t)]}{\partial t} + \frac{\partial \pi_n^d[\hat{p}_n^d(t)]}{\partial \hat{p}_n^d(t)} \frac{\mathrm{d}\hat{p}_n^d(t)}{\mathrm{d}t} = [\hat{p}_n^d(t) - c^d(\phi)] \frac{y_{n\,p_n^*}^d \pi_{n\,p_n p_n}^d \pi_{n\,p_n p_n^*}^d}{B^d} > 0$$

where $B^j = \pi_{n\,p_n p_n}^j \pi_{n\,p_n^* p_n^*}^{*j} - \pi_{n\,p_n p_n^*}^j \pi_{n\,p_n^* p_n}^{*j} > 0; \forall j = \{d, h\}$. The previous expressions are positive. But it seems complex to compare such expressions. We have: $\left|y_{n\,p_n^*}^d\right| > \left|y_{n\,p_n^*}^h\right|$. We also made the assumption that the marginal profit is higher when the R&D is successful (see Assumption 2.5). Then: $[\hat{p}_n^d(t) - c^d(\phi)] > [\hat{p}_n^h(t) - c^h]$. However, it is complex to compare the two last terms $\pi_{n\,p_n p_n}^d \pi_{n\,p_n p_n^*}^d / B^d$ and $\pi_{n\,p_n p_n}^h \pi_{n\,p_n p_n^*}^h / B^h$, especially under nonlinear forms. First order effects are on $y_{n\,p_n^*}^d$, then on $[\hat{p}_n^d(t) - c^d(\phi)]$. The probability that the tariff increases the difference in profit remains high. But we cannot demonstrate that the effect is always positive.

2.B. Impact of Several Policy Instruments on Expected Consumer Surplus

-Table 2.2-

Evolution of the Northern Country's Expected Consumer Surplus with an Import Tariff, a Quality Standard, a Minimum price and an Import Quota

	Import Tariff such as $t = 1$		Quality Standard		Relatively Binding Minimum price such as $p_{min} = \hat{p}_n^{*d} + z$		Strongly binding Minimum price such as $p_{min} = \hat{p}_n^{*h} + z$		Prohibitive Import Quota $q = 0$	
η	$b_i = 2$	$b_i = 3$	$b_i = 2$	$b_i = 3$	$b_i = 2$	$b_i = 3$	$b_i = 2$	$b_i = 3$	$b_i = 2$	$b_i = 3$
0.25	-8.21229	-7.79463	-130.4387	-42.57767	-0.078079	-0.036426	-2.525704	-1.837659	-109.3169	-50.64391
0.5	-8.00433	-7.70639	-123.4294	-39.76177	-0.143377	-0.073230	-4.601448	-2.483103	-105.7439	-49.70164
0.75	-7.56517	-7.51798	-114.4325	-35.80689	-0.177310	-0.099832	-5.927267	-3.029401	-99.62214	-48.05294
1	-6.79448	-7.18616	-103.7716	-30.56763	-0.164147	-0.109847	-3.935780	-2.801909	-90.91091	-45.68118
1.25	-5.55152	-6.65085	-91.95666	-23.86445	-0.081309	-0.094133	4.971923	-0.848251	-79.58434	-42.58450
1.5	-3.63511	-5.82695	(b)	-15.47525	0.104085	-0.03940	25.97255	(c)	-65.66762	-38.79035
1.75	(a)	-4.59141	(a)	-5.124350	(a)	0.0740211	(a)	(c)	(a)	-34.38085
2	(a)	-2.76199	(a)	7.531566	(a)	0.2758692	(a)	(c)	(a)	-29.53812
2.25	(a)	-0.06126	(a)	22.92064	(a)	0.6122734	(a)	(c)	(a)	-24.62717
2.5	(a)	3.946958	(a)	41.57476	(a)	1.1570145	(a)	(c)	(a)	-20.35307

Source: authors.

Note: We set: $c^d(\phi) = c^h + \phi; a_n = 40; a_s = 30; c^h = 6; c^* = 3; \phi = 0.2; g = g^* = 1; F = F^* = 0; z = 0.1$. (a) The condition $b > (1 + \phi\eta)/(1 - \phi\eta)$ no longer holds. (b) The level of R&D is greater than one. (c) The Southern firm's exports are negative under a successful R&D.

2.C. Welfare Analysis

-Table 2.3-

Optimal Policy Instruments When Parameters Vary

			Policy Instrument	Optimal Value	ΔE(W)	ΔE(W*)
$\phi = 0.2$	$b_n = b_s = 2$	$\eta = 0.5$	Import Tariff	16.5508033	183.823613	-256.897891
			Production Subsidy	3.22254028	7.78716801	-20.4513433
			R&D Subsidy	18.4727963	0.01100592	-0.546417
			Quality Standard	-	-211.313788	-312.268763
			Minimum price	16.2666667	1.1875101	-20.169574
			Import Quota	0	85.1563207	-292.945854
		$\eta = 1$	Import Tariff	16.9565435	200.726885	-245.089359
			Production Subsidy	4.00647595	11.4775243	-20.554964
			R&D Subsidy	49.946966	0.53559784	-6.41479308
			Quality Standard	-	-98.1804461	-294.454869
			Minimum price	16.2667	23.4199971	-23.2201051
			Import Quota	0	109.717667	-265.446637
		$\eta = 1.5$	Import Tariff	14.9758	253.037868	-199.319984
			Production Subsidy	6.08087264	23.6015963	-11.4295422
			R&D Subsidy	70.417448	3.77024901	-20.9086297
			Quality Standard	(a)	(a)	(a)

			Minimum price	18.9758242	204.613391	-142.768452
			Import Quota	0	157.365722	-212.902476
	$b_n = b_s = 3$	$\eta = 0.5$	Import Tariff	6.66184031	47.8342226	-95.4290047
			Production Subsidy	2.48623055	6.96309294	-5.53450378
			R&D Subsidy	10.5534091	0.00081367	-0.08308362
			Quality Standard	-	-111.105712	-130.812707
			Minimum price	(b)	0	0
			Import Quota	19.7142	-4.20592691	-121.906172
		$\eta = 1$	Import Tariff	6.6160529	48.4196891	-91.4110881
			Production Subsidy	2.77308089	8.46939228	-5.54889904
			R&D Subsidy	51.8968807	0.15109548	-1.86140376
			Quality Standard	-	-88.4726023	-124.694214
			Minimum price	10.5714286	2.93224468	-6.14906783
			Import Quota	0	-2.14866568	-119.62378
		$\eta = 1.5$	Import Tariff	6.5438914	52.5547558	-81.8642383
			Production Subsidy	3.54120136	13.0938693	-3.48366639
			R&D Subsidy	75.3998268	1.23266161	-6.33003932
			Quality Standard	-	-54.0298708	-109.652165
			Minimum price	10.5438	20.896489	-19.7946113
			Import Quota	0	6.74781467	-104.77343
$\phi = 0.1$	$b_n = b_s = 2$	$\eta = 0.5$	Import Tariff	16.5512526	182.0127	-259.114678
			Production Subsidy	3.08585143	7.21336599	-20.155769
			R&D Subsidy	-1.50253967	1.4456E-05	0.01074565
			Quality Standard	-	-252.250962	-309.85553
			Minimum price	(b)	0	0
			Import Quota	0	79.8616143	-298.995554
		$\eta = 1$	Import Tariff	16.5559191	183.987986	-256.756877
			Production Subsidy	3.23209595	7.83206911	-20.4827615
			R&D Subsidy	21.1926214	0.01556657	-0.6515713
			Quality Standard	-	-209.067972	-311.873928
			Minimum price	16.2666667	1.29264868	-20.6158906
			Import Quota	0	85.4552477	-292.628827
		$\eta = 1.5$	Import Tariff	16.6589619	189.45532	-252.2658
			Production Subsidy	3.5269523	9.15483585	-20.7997863
			R&D Subsidy	37.6040891	0.14054856	-2.69642035
			Quality Standard	-	-157.233862	-306.64598
			Minimum price	23.8968944	74.3164759	-134.87088
			Import Quota	0	95.4051722	-281.424933
	$b_n = b_s = 3$	$\eta = 0.5$	Import Tariff	6.68469614	47.9021165	-96.2353464
			Production Subsidy	2.44161052	6.74865203	-5.39025547
			R&D Subsidy	-17.1143338	0.00039848	0.03179986
			Quality Standard	-	-118.417947	-130.966365
			Minimum price	(b)	0	0
			Import Quota	19.7142	-4.34909786	-126.085379
		$\eta = 1$	Import Tariff	6.6619414	47.8489397	-95.3743411
			Production Subsidy	2.49138048	6.99199091	-5.5429578
			R&D Subsidy	16.120011	0.00213532	-0.13460464
			Quality Standard	-	-110.449222	-130.660664
			Minimum price	(b)	0	0
			Import Quota	19.7142	-4.19334793	-121.534436
		$\eta = 1.5$	Import Tariff	6.63455079	47.9540953	-93.7677789
			Production Subsidy	2.59829226	7.53834851	-5.64980573
			R&D Subsidy	37.4234915	0.03524563	-0.74507873
			Quality Standard	-	-100.295092	-128.520187
			Minimum price	10.5714286	0.41408715	-2.84032507
			Import Quota	19.7142	-4.00875094	-116.11896

Source: authors.

Note: We set: $c^d(\phi) = c^h + \phi; a_n = 40; a_s = 30; c^h = 6; c^* = 3; g = g^* = 1; F = F^* = 0$. (a) The level of R&D is greater than one. (b) The optimal minimum price equals the free trade level of the Southern firm's price of exports when the R&D is successful. Therefore, the domestic welfare does not vary as compared to free trade.

-CHAPTER 3-

Policy Instruments, Patents and International Technology Diffusion in a North-South Duopoly[16]

3.1. Introduction

Economic development of developing countries depends on technology diffusion. Foreign sources of technology are crucial for these countries because domestic R&D expenditures are low. The share of domestic R&D expenditures in their GDP is always lower than two percent (source: World Bank WDI).

There is some debate about the way to accelerate technology diffusion from rich countries to developing countries (see the review of the economic literature on technology diffusion in Chapter 0, Subsection 0.4.3). Therefore, it would be interesting to study how policy instruments implemented by both rich and developing countries influence the speed of technology diffusion.

The objective of this chapter is to evaluate the impact of policy instruments on technology diffusion by using a simple theoretical framework. We also research the impact on other strategic variables like profits, consumer surplus and national welfares. We use a framework which is close to **Miyagiwa and Ohno (1997)** that we described in the general introduction. We consider a North-South duopoly like in Chapters 1 and 2. But we design an inter-temporal model in which time is continuous. A first difference with respect to **Miyagiwa and Ohno (1997)** is that, initially, the Northern firm already benefits from the new technology while the Southern firm uses the old technology. Developed countries benefit from a larger capital endowment while developing countries benefits from a larger labor endowment.

Here, the new technology diffusion is a transfer from the Northern firm to the Southern firm. It occurs through the bilateral trade between the North and the South. The economic literature has considered endogenous technology diffusion. For example, **Tanaka, Iwaisako and Futagami (2007)** design an endogenous growth model by using a North-South framework in which technology diffusion from the North to the South occurs through licensing. Northern firms file patents if innovations are successful. **Iwaisako, Tanaka and Futagami (2011)** design another endogenous growth model in which the main determinant of technology diffusion is FDI. In this chapter, we consider a simple case in which technology diffusion is given.

We study the case in which the Northern firm files a patent to increase the monopoly period with the new technology. A patent leads to protection of information for the Northern firm and so slows down technology diffusion. The Southern firm can use the

[16] This study has been published in *The International Trade Journal* (**Berthoumieu, 2016**).

new technology only upon the term of the patent. In this sort of North-South framework, we consider that the Northern firm's patent always slows down the new technology diffusion to the Southern firm. Patents involve disputes among firms or countries. For example, in 2012, the technology war between Google and Apple illustrates that patents are a way to prevent a firm from being competitive in a specific market and that firms often file lawsuit because of patent infringements.[17]

We consider a simple case in which a patent involves the protection of a process. We take into account the fact that the Northern firm faces a patent filing cost. Papers that study the optimal patent length generally do not introduce this variable. Papers that introduce patent cost study the effect of the patent as compared to a situation without patent but do not study the optimal patent length. Here, we attempt to implement a new structure by applying both patent length and patent filing cost. Such a cost increases with the patent term because the Northern firm has to pay maintenance fees to keep the patent in force. Patents may involve prosecutions that increase expenditures.

As a consequence, the Northern firm selects patent expenditures by choosing the patent term. *"The term of protection available shall not end before the expiration of a period of twenty years counted from the filing date* (Source: Article 33 of TRIPs Agreements)*."* Pharmaceutical firms have the opportunity to benefit from a Supplementary Protection Certificate that protects innovations for further five years. Generally, when a firm files a patent, there are annual maintenance fees to be paid. This is the reason why the length of protection may end before the stated twenty years. Moreover, firms can file utility models that have fewer requirements instead of classic patents. Utility models are one particular type of patent. They are less stringent in terms of protection length and filing cost. Usually, the term of utility model is around ten years. The Northern firm's patent only slows down diffusion because technology diffusion is not avoidable (**Keller, 2002**). Consequently, an infinite patent length is not possible.

We analyze the effect of policy instruments on the speed of the new technology diffusion through the impact on the Northern firm's patent length. We focus on the same instruments as in Chapters 1 and 2. We provide a first extension with the analysis of the impact of the Southern government's policy instruments. Of course, we realize that this section should be dramatically improved in future research.

We also study the impact of two new policy instruments:

- A patent subsidy implemented by the Northern government. The Northern government can subsidize its domestic firm's patent expenditures in order to reduce the Northern firm's patent filing cost. In 2002, the Belgian government implemented subsidies for small and medium-sized businesses *"to register and to maintain a patent."* In 2010, the subsidy rate achieved 70 percent of the patent filing cost (Source: Europa, European Commission Website). **Munari and Xu (2011)** conduct an overview of ten experiences of patent subsidies throughout the 2000s: *"the use of*

[17] See the newspaper article "In technology wars, using the patent as a sword" in *The New York Times* (October 7, 2012).

patent subsidies, in particular in favor of SMEs, has recently gained an increased attention by policy-makers [p. 5].*"*

- A public R&D investment implemented by the Southern government. Today governments in the South would be interested in policies that foster innovations. Southern countries' R&D expenditures are low compared to Northern countries'. As a consequence, we study a case in which the Southern government implements a public R&D program. Instead of using the old technology, the Southern firm benefits from an intermediate technology before the new technology diffusion.

Finally, we introduce a second possible extension with the implementation of a licensing contract between the two firms. In this case, the speed of the new technology diffusion no longer depends on the patent length but on the date of the licensing contract.

The results of this chapter show that policy instruments implemented by the Northern country slow down technology diffusion between the two firms by increasing the monopoly period with the new technology except for an import quota that accelerates the new technology diffusion. Furthermore, the Southern government's policy instruments accelerate technology diffusion by reducing the monopoly period with the new technology and increase the domestic national welfare. Each policy always increases the domestic country's national welfare up to an optimal level.

Section 3.2 introduces the model. Section 3.3 analyzes the impact of the Northern government's policy instruments on the speed of the new technology diffusion. Section 3.4 provides a first extension with the analysis of the impact of policy instruments implemented by the Southern government. Section 3.5 presents the welfare analysis. Section 3.6 introduces a second extension: a licensing contract between the two firms. Section 3.7 concludes.

3.2. The Model

Let us suppose a dynamic model in which time is continuous and defined over $[0,\infty)$. Initially, the Northern firm benefits from a new technology denoted by $\overline{\mu}$ while the Southern firm only uses an old technology denoted by $\underline{\mu}^*$. Here, the new technology diffusion is defined by the technology transfer from the Northern firm to the Southern firm. Such a diffusion occurs at period T over $[0,\infty)$. The Southern firm can use the new technology $\overline{\mu}^*$ over $[T,\infty)$. The Northern firm benefits from $\overline{\mu}$ over $[0,\infty)$. Here, we consider that the new technology diffusion occurs due to information diffusion via telecommunications such as the Internet and due to the existence of a bilateral trade between the North and the South. Nevertheless, the level of the bilateral trade between the North and the South does not influence the speed of technology diffusion.

We use the same linear functions for production costs where c (c^*) denote the Northern (Southern) firm's marginal cost.

Assumption 3.1: Each firm's technological endowment influences its marginal cost: $c = c(\mu)$, with $\mu = \overline{\mu}$, $c^* = c^*(\mu^*)$, with $\mu^* = \underline{\mu}^*, \overline{\mu}^*$. We have: $c^*\left(\underline{\mu}^*\right) > c^*\left(\overline{\mu}^*\right)$. The value of c^* changes at time T.

Such a structure relates to an empirical example, for instance the agricultural sector. The assumption of the existence of two markets works because the level of bilateral trade between Northern and Southern countries is high in the agricultural sector. Northern and Southern producers also differ in productivity. Developing countries' agricultural productivity is lower than developed countries' (**Fulginiti and Perrin, 1999**). The role of technological endowment is crucial. For example, **O'Neill (2000)** mentions that *"the application of ergonomics differs between IDCs* [Industrially Developing Countries] *and IACs* [Industrially Advanced Countries] *particularly through the limited infrastructure in IDCs to support ergonomics activity and interventions* [p. 631]*."* Another interesting feature of the agricultural sector is that producers from rich countries file patents to protect their technologies. For example, developed countries' intellectual property makes it difficult for developing countries to access modern agricultural biotechnologies (**Adenle et al., 2012**). Furthermore, firms files patents on both products and processes: nanotechnologies, biotechnologies, plants (**Alendete-Saez et al., 2014**). In this chapter, we consider a process patent on a new technology.

Assumption 3.2: At each point in time, there is Cournot competition on both markets. Each firm sells a homogenous good.

Consider a two-stage model. At each point in time, both firms select the level of output that maximizes their static profit flows. The Northern firm files a patent to increase the monopoly period with the new technology. The patent filing cost increases with the patent length. Then, the Northern firm selects its patent-related expenditures (i.e. the patent length) that maximize its discounted sum of profit flows.

At each point in time, the static profit flows are:

$$\pi(x_n, x_s, y_n, y_s) = x_n p_n(x_n + y_n) + x_s p_s(x_s + y_s) - c(\overline{\mu})(x_n + x_s) - g x_s \tag{3.1}$$

$$\pi^*(x_n, x_s, y_n, y_s) = y_n p_n(x_n + y_n) + y_s p_s(x_s + y_s) - c^*(\mu^*)(y_n + y_s) - g^* y_n; \forall \mu^* = \left\{\underline{\mu}^*, \overline{\mu}^*\right\} \tag{3.2}$$

Consider the same specific linear inverse demand functions: $p(X_n) = a_n - X_n$, $p(X_s) = a_s - X_s$. Each firm selects the optimal levels of domestic sales and exports that maximize their profit. In this model, technology diffusion influences the level of the Southern firm's marginal cost c^*. Equilibrium expressions are the same as Equations (1.6), (1.7) and (1.8) in Chapter 1. We search the effect of c^* on domestic sales, exports, prices and profits to determine the effect of the Southern firm's technological endowment. We can easily demonstrate that:

- The Southern firm's marginal cost increases (reduces) the Northern (Southern) firm's domestic sales and exports.
- Each market price increases with the Southern firm's marginal cost.
- The Northern (Southern) firm's profit increases (decreases) with the Southern firm's marginal cost.

The Northern firm enjoys a monopoly with the new technology until T and files a patent at time 0 in the Northern country's office in order to increase such a monopoly. It involves an industrial protection on the Northern market while the Southern firm is not able to discover the new technology by itself in its domestic country. We omit the existence of a patent filed in the South. Firms generally filed patents in developed countries' patent offices like the European Patent Office (EPO). The period $[0, T)$ is called the monopoly period.

The patent filing engenders a filing cost which increases with the said patent length. The variable k denotes the Northern firm's expenditures needed to implement the patent. It also denotes the patent length. Consider that such expenditures are realized at each point in time over $[0, T)$. They relate to maintenance fees. Such a consideration is credible because patentee firms pay maintenance fees on a yearly basis: they choose to maintain the patent in force or not. We consider constant expenditures at each point in time.

Nevertheless, a criticism may be raised against the fact that the level of k increases with the patent length. Empirically, annual maintenance fees do not depend on the patent length. The total cost of the patent depends on it. Such a total cost would equal the total discounted sum of fees k paid at each point in time over $[0, T)$. The monopoly period with the new technology would depend on such a discounted sum. But it looks complex, if not impossible, to solve the model in this case. We consider that the level of patent expenditures paid at each point in time increase with the patent length in order to simplify the demonstration.

Patent expenditures also involve public revenues for the Northern government because they are paid to a public national patent office. An increase in the patent length leads to an increase in the Northern government's public revenues.

Assumption 3.3: The Northern firm's monopoly period T with the new technology depends on the patent length i.e. the patent expenditures k: $T = T(k)$. T increases with k: $T'(k) = \mathrm{d}T(k)/\mathrm{d}k > 0$.

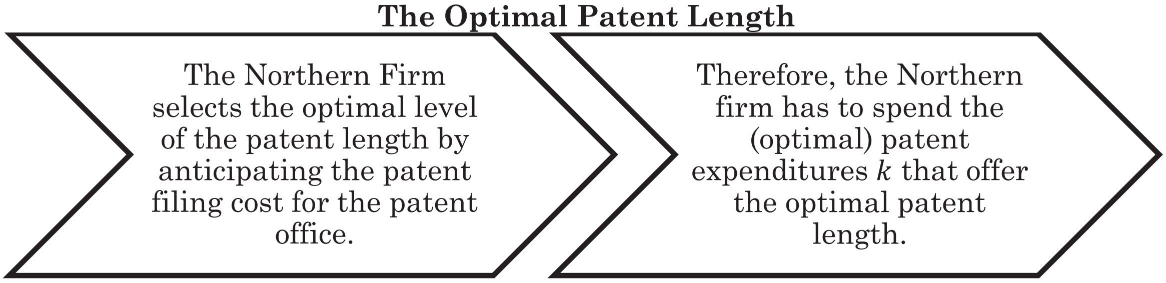
Without patent, the Northern firm benefits from a positive monopoly with the new technology: $T(0) > 0$. With the patent, such a monopoly is greater: $T(k) > T(0); \forall k > 0$.

Assumption 3.4: The Northern firm is encouraged to file the patent: $\hat{\pi}\left(\underline{\mu}^*\right) - k > \hat{\pi}(\overline{\mu}^*)$.

Since the Northern firm pays patent fees at each point in time, it has no reason to file the patent, otherwise. The Northern firm selects the optimal level of patent expenditures k by choosing the optimal level of patent length (see Figure 3.1).

-Figure 3.1-

The Optimal Patent Length



Source: author.

A share of the economic literature has studied the case in which an optimal patent length maximizes the domestic country's social welfare (**Futagami and Iwaisako, 2007**). Here, it only maximizes a discounted sum of profit flows, denoted by Π, with respect to k by anticipating the previous static results:

$$\max_{k\geq 0} \Pi(k) = \int_0^{T(k)} e^{-i\tau}\left[\hat{\pi}\left(\underline{\mu}^*\right) - k\right] \mathrm{d}\tau + \int_{T(k)}^{\infty} e^{-i\tau}\hat{\pi}(\overline{\mu}^*)\mathrm{d}\tau \tag{3.3}$$

where i denotes an exogenous interest rate that discounts flows. Let us consider that both the Northern firm and the Northern government cannot influence the level of such an interest rate. Time is denoted by τ. We use exponentials in order to discount profit flows when time is continuous. The integral becomes:

$$\max_{k\geq 0} \Pi(k) = \frac{\left[1-e^{-iT(k)}\right]\left[\hat{\pi}\left(\underline{\mu}^*\right)-k\right]+e^{-iT(k)}\hat{\pi}(\overline{\mu}^*)}{i} \tag{3.4}$$

The first order condition $\Pi_k = 0$ involves:[18]

$$\frac{\left[1-e^{-iT(k)}\right]}{iT'(k)e^{-iT(k)}} + k = \hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*) \tag{3.5}$$

Since the Northern firm selects the optimal level of patent expenditures, we have to consider that the second order condition is verified:

$$\Pi_{kk} = e^{-iT(k)}\left\{[T''(k) - iT'(k)^2]\left[\hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*)\right] - 2T'(k)\right\} < 0$$

The Northern firm selects a non-optimal level of k, otherwise. The sign of $T''(k)$ is unknown. It seems intuitive to consider a linear relationship between the monopoly period T and the patent expenditures k i.e. $T^{''} = 0$. Nevertheless, we may also consider $T^{''} < 0$ because the Southern firm may benefit from the diffusion of an alternative modern technology that is not patented over time. On the other hand, it seems complex to consider $T^{''} > 0$. Hence, we have: $T^{''} \leq 0$. In the body of the chapter, we use a general form for the function T. But we will use a specific linear function for the welfare analysis.

We denote by $K(k)$ the left side of (3.5). We have: $K(k) = \hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*)$. Since $T^{''} \leq 0$, the function K increases with k:

$$K'(k) = \frac{\left[1-e^{-iT(k)}\right]\left[iT'(k)^2-T''(k)\right]}{iT'(k)^2e^{-iT(k)}} + 2 > 0 \tag{3.6}$$

A simple interpretation of (3.6) stems from rewriting as: $k = \psi\left[\hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*)\right]$ with $\partial\psi/\partial\left[\hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*)\right] > 0$. Hence, k increases with the difference in profit $\left[\hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*)\right]$. In this chapter, the Northern firm's difference in profit is defined as the difference between the Northern firm's static profit when $\mu^* = \underline{\mu}^*$ and its static profit when $\mu^* = \overline{\mu}^*$.

[18] Subscripts denote partial derivatives for Π_k.

The difference in profit equals:

$$\hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*) = \frac{\left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]\left[2a_n + 2a_s - 8c(\overline{\mu}) + 2c^*\left(\underline{\mu}^*\right) + 2c^*(\overline{\mu}^*) - 4g + 2g^*\right]}{9} \tag{3.7}$$

The maximum patent length is determined by patent legislation because it generally equals twenty years. Each year, the patentee firm may decide whether or not to maintain the patent in force. The firm has to pay further annual maintenance fees if it decides to keep the patent in force (**Pakes, 1986**). The patent is cancelled, otherwise. Since the maximum patent length generally equals twenty years, we should set a maximum monopoly period with the new technology as $\overline{T}$ such as $T(k) < \overline{T}$.

Empirically, the patent length often ends before twenty years. In 2012, *"the available data show that more than half of the applications … remained in force for at least eight years after the application data. Approximately 18.5 percent of these patents lasted the full 20-year patent term* [**WIPO, 2013**, p. 84]*."* Patentees have to pay annual maintenance fees while the industrial protection effect of the patent decreases over time. Furthermore, a patented technology is no longer a "new" technology twenty years later. Therefore, we consider that there is always an interior solution $\hat{k}$ such as $T(\hat{k}) < \overline{T}$, in order to simplify the demonstration.

3.3. Policy Instruments Implemented by the Northern Government

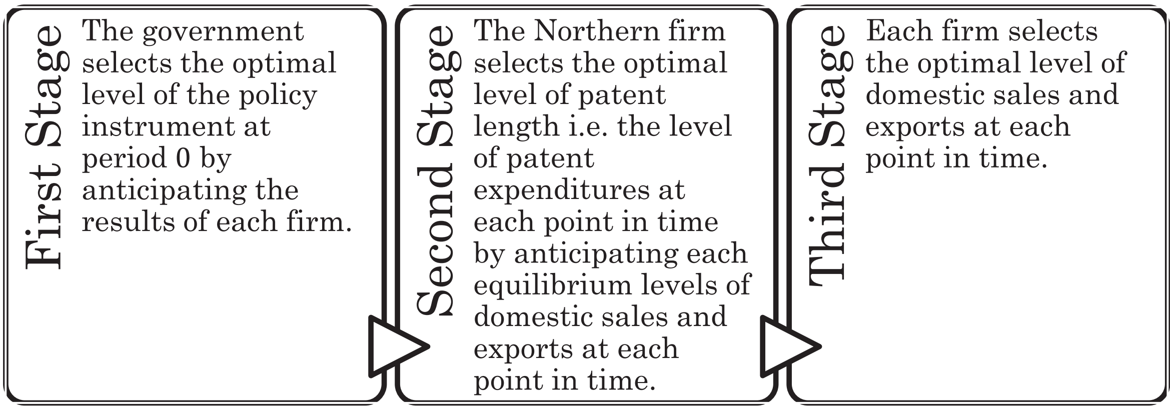
Let us study the impact of policy instruments implemented by the Northern government: an import tariff, a production subsidy, a patent subsidy and an import quota.

Assumption 3.5: Policy instruments are implemented over $[0, \infty)$, except for the patent subsidy implemented over $[0, T)$. The Northern government sets the level of the policy instrument at period 0. Such a level remains the same over $[0, \infty)$.

The Northern government may be encouraged to implement policy instruments for political reasons. The Northern government tries to implement an instrument that increases the Northern country's national welfare as compared to the initial case in Section 3.2. An instrument that increases the consumer surplus is politically desirable. We make a welfare analysis in Section 3.5 to ascertain whether or not governments are encouraged to implement each policy instrument. The structure of the model is the following (see Figure 3.2).

-Figure 3.2-

Structure of the Dynamic Model



Source: author.

First, the government selects the optimal value of the policy instrument by anticipating the equilibrium levels of domestic sales, exports, prices and profits flows of each firm and the Northern firm's patent length. Hence, the Northern government maximizes the Northern country's national welfare W which is given by: $\mathsf{W} = \Pi + \mathsf{CS} + \mathsf{PR}$, where CS now denotes the Northern discounted consumer surplus, and PR the Northern discounted public revenues. Second, the Northern firm selects the optimal level of patent expenditures $\hat{k}$ at period 0 by anticipating each static equilibrium level of domestic sales, exports and profit flows. Third, each firm selects the optimal level of domestic sales and exports at each point in time.

We solve the model by starting with the third stage for each instrument. Then, we find the optimal level of patent expenditures $\hat{k}$. Finally, we find the optimal level of the public policy instrument because we need to know the equilibrium expression for each variable.

3.3.1. An Import Tariff, a Production Subsidy and a Patent Subsidy

We have already studied the economic impact of an import tariff and a production subsidy on domestic sales, exports, prices and static profits in previous chapters. The patent subsidy has no direct impact. The effect is only indirect by impacting the patent length.

Proposition 3.1: The Northern firm's patent length increases with the implementation of an import tariff, a production subsidy and a patent subsidy. Consequently, the Northern firm has to increase its patent expenditures k. The monopoly period T also increases. These policy instruments slow down the new technology diffusion from the North to the South.

Proof: □ Let us study the impact of each policy instrument. We are looking for the impact on the import tariff and the production subsidy on the difference in profit. Then, we study the impact of the patent subsidy.

- The economic impact of the implementation of the Northern government's import tariff is the same as that of an increase in the Southern firm's unit transport cost g^*. According to Equation (3.3), we have:

$\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,t\right)-\hat{\pi}\left(\overline{\mu}^*,t\right)\right]}{\mathrm{d}t}=\frac{2\left[c^*\left(\underline{\mu}^*\right)-c^*\left(\overline{\mu}^*\right)\right]}{9}>0$

The tariff increases the difference in profit. The Northern government's tariff t reduces competition from the Southern firm on the Northern market. The Northern firm benefits from a higher market share on its domestic market. The positive impact of the drop in y_n on π increases with x_n: $\partial\pi/\partial y_n=-x_n<0$. The domestic sales x_n are higher before the new technology diffusion. The Northern firm increases its patent expenditures.

- The economic impact of the implementation of the Northern government's production subsidy is the same as that of a drop in the Northern firm's marginal cost $c(\overline{\mu})$. We have:

  $\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,s\right)-\hat{\pi}\left(\overline{\mu}^*,s\right)\right]}{\mathrm{d}s}=\frac{8\left[c^*\left(\underline{\mu}^*\right)-c^*\left(\overline{\mu}^*\right)\right]}{9}>0$

  The difference in profit increases with the production subsidy. The Northern government's production subsidy increases k because the positive effect on its profit is higher when the Southern firm uses the old technology (its output is greater). The production subsidy leads to further revenues for the Northern firm. Such revenues increase with the level of output (x_n+x_s). The Northern firm increases the patent length to benefit from higher market shares and revenues. The subsidy s slows down the new technology diffusion.
- Finally, let us study the impact of the patent subsidy. The said patent is denoted by φ. The static profit flows expressions do not change. Unlike a production subsidy, it does not directly affect outputs, price and profit flows. But it does reduce the patent filing cost. The real cost now equals: $(1-\varphi)k$. The Northern firm's discounted sum of profit flows is now:

  $\max_{k\geq 0}\Pi(k,\varphi)=\int_0^{T(k)}e^{-i\tau}\left[\hat{\pi}\left(\underline{\mu}^*\right)-(1-\varphi)k\right]\mathrm{d}\tau+\int_{T(k)}^{\infty}e^{-i\tau}\hat{\pi}\left(\overline{\mu}^*\right)\mathrm{d}\tau$

  The first order condition leads to:

  $K(k)=\frac{\hat{\pi}\left(\underline{\mu}^*\right)-\hat{\pi}\left(\overline{\mu}^*\right)}{1-\varphi}$

  Therefore, k decreases with $(1-\varphi)$ i.e. it increases with the patent subsidy φ. Such a subsidy reduces the Northern firm's total patent filing cost. The firm benefits from further revenues that increase with its expenditures. It explains why the firm is encouraged to increase k. The monopoly period with the new technology increases when the total patent filing cost does not vary. In this sense, a patent subsidy is more efficient than a production subsidy to encourage a firm to protect its technological advantage.

These policy instruments implemented by the Northern government always slow down the new technology diffusion by increasing the patent length. □

The sign of the impact of "at-the-border" policy instruments like an import tariff is the same as that of the impact of "behind-the-border" policy instruments like a production subsidy. But "behind-the-border" policy instruments seem to be more efficient because the impact of the production subsidy is greater.

The form of inverse demand functions may influence the results. We cannot demonstrate that the production subsidy and the import tariff increase the difference in profit by using general forms (see Appendix 3.A). Using any other linear form, the impact is always positive. But under nonlinear forms, the results may differ owing to second order effects.

3.3.2. The Specific Case of an Import Quota

Proposition 3.2: The Northern firm decreases the patent length with the implementation of both a relatively binding and a strongly binding quota by the Northern government. The Northern government's quota accelerates the new technology diffusion.

Proof: □ Let us study two cases (see Section 1.3.5 in Chapter 1).

- First case: $\hat{y}_n\left(\underline{\mu}^*\right) \leq q < \hat{y}_n(\overline{\mu}^*)$. The quota is relatively binding because it is only binding over $[T, \infty)$. The effect of the quota is null over $[0, T)$. The Northern firm's profit increases as compared to free trade only after the new technology diffusion. Therefore, the difference in profit is lower: $\hat{\pi}\left(\underline{\mu}^*, q\right) - \hat{\pi}(\overline{\mu}^*, q) < \hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*)$.
- Second case: $q < \hat{y}_n\left(\underline{\mu}^*\right)$. The quota is strongly binding because it reduces the level of the Southern firm's exports regardless of its technological endowment. The Northern firm's profit increases as compared to free trade over $[0, \infty)$. With the quota, the difference in profit equals:
  $\hat{\pi}\left(\underline{\mu}^*, q\right) - \hat{\pi}(\overline{\mu}^*, q) = \frac{\left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]\left[\hat{x}_s\left(\underline{\mu}^*\right) + \hat{x}_s(\overline{\mu}^*)\right]}{3}$
  According to Equation (3.3), under free trade, the difference in profit equals:
  $\hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*) = \frac{\left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]\left[\hat{x}_n\left(\underline{\mu}^*\right) + \hat{x}_n(\overline{\mu}^*) + \hat{x}_s\left(\underline{\mu}^*\right) + \hat{x}_s(\overline{\mu}^*)\right]}{3}$
  The difference in profit decreases with a very restrictive quota as compared to free trade since $\left[\hat{x}_n\left(\underline{\mu}^*\right) + \hat{x}_n(\overline{\mu}^*)\right] > 0$.

The difference in profit decreases as compared to free trade regardless of the level of the quota. Therefore, the Northern firm reduces the patent length. The Northern government's quota accelerates the new technology diffusion. □

Comparing the impact of an import quota and that of an import tariff is interesting. The effect of the first (second) on the patent length is negative (positive) while both instruments reduce competition from the Southern country. With the quota, the Northern firm's profit earned on the Northern market no longer depends on the Southern firm's technological endowment. With the tariff, it still depends on such a technological endowment. This is the main difference between the two policy instruments and the reason why the Northern firm reduces the patent length. Such a result means that Voluntary Exports Restraints (VER) implemented by the Southern country may be a way to accelerate the new technology diffusion.

3.4. First Extension: The Southern Government's Policy Instruments

In Chapters 1 and 2, the main issue has been to find ways to enhance competitiveness in industrialized countries for policy makers when they face growing competition from low cost countries. We have focused on the Northern government's policy instruments. Here, the main issue is no longer rich countries' competitiveness but developing countries' economic development through technology diffusion. Nevertheless, we realize that our contribution is limited and should be dramatically improved in future research. We only extend the general framework.

The Southern government may implement policy instruments in order to accelerate the new technology diffusion. The structure is the same as that in Figure 3.2. We study the impact of the implementation of an import tariff, a production subsidy, an import quota and a public R&D investment.

3.4.1. An Import Tariff and a Production Subsidy

Proposition 3.3: An import tariff and a production subsidy implemented by the Southern government accelerate the new technology diffusion by reducing the patent length. When each government implements an import tariff (a production subsidy), the Northern firm reduces (increases) the patent length. A tariff war (subsidy war) accelerates (slows down) the new technology diffusion.

Proof: □ We denote by t^* the import tariff and s^* the production subsidy implemented by the Southern government. Let us study the impact of these instruments on the Northern firm's difference in profit.

- The economic impact of the Southern government's tariff is the same as that of an increase in the Northern firm's marginal cost g. We have:
  $$\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,t^*\right)-\hat{\pi}\left(\overline{\mu}^*,t^*\right)\right]}{\mathrm{d}t^*}=-\frac{4\left[c^*\left(\underline{\mu}^*\right)-c^*\left(\overline{\mu}^*\right)\right]}{9}<0$$
  The difference in profit decreases with the implementation of the Southern government's import tariff. Now, let us study the case in which each government implements an import tariff. We have:
  $$\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,t,t^*\right)-\hat{\pi}\left(\overline{\mu}^*,t,t^*\right)\right]}{\mathrm{d}t}+\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,t,t^*\right)-\hat{\pi}\left(\overline{\mu}^*,t,t^*\right)\right]}{\mathrm{d}t^*}=-\frac{2\left[c^*\left(\underline{\mu}^*\right)-c^*\left(\overline{\mu}^*\right)\right]}{9}<0$$
  Such a result means that a tariff war between the two countries accelerates the new technology diffusion since the levels of tariff are the same in the two countries. The Southern government's tariff is a further transport cost for the Northern firm and involves a direct cost. The Northern government's tariff only involves an indirect gain for the Northern firm via the drop in competition from the Southern firm on the Northern market.
- The economic impact of the Southern government's production subsidy is the same as that of a drop in the Southern firm's marginal cost $c^*(\mu^*)$. We have:
  $$\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,s^*\right)-\hat{\pi}\left(\overline{\mu}^*,s^*\right)\right]}{\mathrm{d}s^*}=-\frac{4\left[c^*\left(\underline{\mu}^*\right)-c^*\left(\overline{\mu}^*\right)\right]}{9}<0$$
  The difference in profit decreases with the Southern government's production subsidy. Let us study the case in which each government implements a production subsidy. We have:
  $$\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,s,s^*\right)-\hat{\pi}\left(\overline{\mu}^*,s,s^*\right)\right]}{\mathrm{d}s}+\frac{\mathrm{d}\left[\hat{\pi}\left(\underline{\mu}^*,s,s^*\right)-\hat{\pi}\left(\overline{\mu}^*,s,s^*\right)\right]}{\mathrm{d}s^*}=\frac{4\left[c^*\left(\underline{\mu}^*\right)-c^*\left(\overline{\mu}^*\right)\right]}{9}<0$$

The difference in profit increases. The reason is that the Northern government's production subsidy involves a direct positive gain for the Northern firm while the Southern government's production subsidy only involves an indirect cost via the increase in competition from the Southern firm.

An import tariff and a production subsidy implemented by the Southern government slow down the new technology diffusion because the Northern firm reduces the patent length. But a tariff war between the two countries accelerates the new technology diffusion while a subsidy war slows it down. □

Nevertheless, we cannot prove that these results hold with general forms for inverse demand functions (see Appendix 3.A).

3.4.2. An Import Quota

Now let us study the impact of the implementation of an import quota by the Southern government. We denote by q^* such a quota, i.e. the maximum level of the Northern firm's exports.

Proposition 3.4: An import quota implemented by the Southern government accelerates the new technology diffusion because the Northern firm reduces the patent length as compared to free trade. The result holds with both a relatively binding and a strongly binding quota.

Proof: □ Let us study the two cases:

- First case: $\hat{x}_s(\overline{\mu}^*) \leq q^* < \hat{x}_s\left(\underline{\mu}^*\right)$. The quota is relatively binding because it only reduces the Northern firm's exports over $[0, T)$. The Northern firm's profit only decreases when $\mu^* = \underline{\mu}^*$. The difference in profit decreases with a relatively binding quota: $\hat{\pi}\left(\underline{\mu}^*, q^*\right) - \hat{\pi}(\overline{\mu}^*, q^*) < \hat{\pi}\left(\underline{\mu}^*\right) - \hat{\pi}(\overline{\mu}^*)$.
- Second case: $q^* < \hat{x}_s(\overline{\mu}^*)$. The quota is strongly binding because it reduces the Northern firm's exports regardless of the Southern firm's technology endowment. The Northern firm's profit decreases over $[0, \infty)$. With the Southern government's quota, the difference in profit equals:
  $$\hat{\pi}\left(\underline{\mu}^*, q^*\right) - \hat{\pi}(\overline{\mu}^*, q^*) = \left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]\left[\frac{\hat{x}_n\left(\underline{\mu}^*\right) + \hat{x}_n(\overline{\mu}^*)}{3} + \frac{q^*}{2}\right]$$
  The implementation of the quota reduces the difference in profit as compared to free trade since $\left[\hat{x}_s\left(\underline{\mu}^*\right) + \hat{x}_s(\overline{\mu}^*)\right] > 2q^*/3$.

The difference in profit decreases as compared to free trade regardless of the level of the quota. Therefore, the Northern firm reduces the patent length and the patent expenditures k. The Southern government's quota accelerates the new technology diffusion. Such a result means that a quota war between the two governments would involve an increase in the speed of the new technology diffusion as compared to free trade. □

The Southern government's quota reduces the Northern firm's exports but does not change the outcome on the Northern market. We have: $\partial\pi/\partial q^* = p_s - c(\overline{\mu}) - g - q^*$. The negative effect of a binding quota increases with the Southern market price. Such a market price is higher when the Southern firm uses the old technology. Therefore, the Northern firm is encouraged to reduce the patent length.

3.4.3. A Public R&D Investment

Finally, let us study the impact of a public R&D investment implemented by the Southern government. Under the initial case, the Southern firm does not invest in R&D because the cost of such an investment is too high. Southern economies' R&D expenditures are lower than Northern economies' because skilled labor and modern telecommunications are scarce and costly. The Southern government can, however, encourage innovations in its domestic country.

Consider a cost-reducing R&D investment denoted by r^* and implemented at period 0. We denote by v^* the unit R&D cost. We consider that the Southern government directly invests in R&D by implementing a public R&D program. The Southern firm benefits from another technological endowment owing to such public innovations. In this case, the Southern government selects the optimal level of public R&D that maximizes the Southern country's national welfare by anticipating the Northern firm's patent expenditures.

The Southern firm now benefits from an intermediate technology over $[0, T)$. We cannot consider that the Southern firm benefits from the new technology at period 0. The dynamic structure would be unnecessary, otherwise. Furthermore, it would be less credible because the speed of technology diffusion often depends on rich countries' behaviors. Southern countries' innovations are too low. These countries generally benefit from foreign sources of productivity (**Keller, 2004**).

Assumption 3.6: The Southern government implements an R&D investment denoted by r^* at period 0 that reduces the marginal cost c^* over $[0, T)$. The Southern firm can use an intermediate technology over $[0, T)$. The returns of the R&D investment are decreasing: $\mathrm{d}c^*/\mathrm{d}r^* < 0; \mathrm{d}^2c^*/\mathrm{d}r^{*2} \geq 0$. The function of marginal cost is convex.

We denote by $\mu^*_{r^*}$ the intermediate technology that depends on the level of R&D investments r^* such as: $c^*\left(\underline{\mu}^*\right) > c^*[\mu^*_{r^*}(r^*)] > c^*(\overline{\mu}^*)$. Therefore, the Southern firm's marginal cost $c^*[\mu^*_{r^*}(r^*)]$ is endogenous. When the new technology diffusion occurs, the R&D investment no longer influences the Southern firm's marginal cost. The Southern firm's static profit expression is the same as that in Equation (3.2). But we have $\mu^* = \mu^*_{r^*}(r^*)$ over $[0, T)$. According to the impact of c^* on each variable, we can easily find the impact of r^*. The R&D investment increases (reduces) the Southern (Northern) firm's domestic sales, exports and profit flows. It also reduces the market prices. The effect on the total supply on each market is positive. Therefore, there is a direct positive impact on each country's consumer surplus.

The Northern firm's discounted sum of profit flows is now:

$$\max_{k\geq 0} \Pi(k, r^*) = \int_0^{T(k)} e^{-i\tau}\hat{\pi}[\mu^*_{r^*}(r^*)]\mathrm{d}\tau + \int_{T(k)}^{\infty} e^{-i\tau}\hat{\pi}(\overline{\mu}^*)\mathrm{d}\tau - k \quad (3.8)$$

The Southern firm's discounted sum of profit flows increases with the public R&D investment. But the Southern firm does not maximize such a discounted sum. The Southern government selects the optimal level of R&D that maximizes the Southern country's national welfare.

Proposition 3.5: The Southern government's public R&D investment accelerates the new technology diffusion because the Northern firm reduces the patent length.

Proof: □ Differentiating the Northern firm's first order condition $\Pi_k = 0$, we have:

$$\frac{\mathrm{d}k}{\mathrm{d}r^*} = -\frac{\Pi_{kr^*}}{\Pi_{kk}} < 0, \text{ with } \Pi_{kr^*} = T'(k)e^{-iT(k)}\frac{2\{\hat{x}_n[\mu^*_{r^*}(r^*)] + \hat{x}_s[\mu^*_{r^*}(r^*)]\}}{3}\frac{\mathrm{d}c^*[\mu^*_{r^*}(r^*)]}{\mathrm{d}r^*} < 0$$

The Northern firm's patent expenditures decrease with the public R&D investment. The two variables are strategic substitutes. The Northern firm reduces its patent expenditures. The monopoly period involves a lower gain for the Northern firm because the Southern firm uses an intermediate technology. □

We did not study the case in which the Southern country's R&D investment influences the date of the new technology diffusion. We could have considered a case in which the Southern country implements an R&D program at period 0 to discover the new technology as soon as possible. The monopoly period with the new technology would decrease with such an R&D program. But the effect of the patent would be null because the Southern country could discover the new technology by itself. The issue of the model would no longer make sense in this case.

3.5. Welfare Analysis

Previously, we have studied the impact of policy instruments on the speed of the new technology diffusion from the Northern firm to the Southern firm. Now, let us analyze the economic impact of each instrument via the effect on profits, consumer surplus, public revenues and national welfares.

3.5.1. General Framework under the Initial Case

We use a linear function for the monopoly period T: $T(k) = \theta + \omega k$. The Northern firm selects the optimal level of patent expenditures $\hat{k}$. The equilibrium expressions of discounted sum of profit flows are:

$$\hat{\Pi}(\hat{k}) = \frac{\left[1-e^{-iT(\hat{k})}\right]\left[\hat{\pi}\left(\underline{\mu}^*\right)-\hat{k}\right]+e^{-iT(\hat{k})}\hat{\pi}(\overline{\mu}^*)}{i}; \hat{\Pi}^*(\hat{k}) = \frac{\left[1-e^{-iT(\hat{k})}\right]\hat{\pi}^*\left(\underline{\mu}^*\right)+e^{-iT(\hat{k})}\hat{\pi}^*(\overline{\mu}^*)}{i}$$

The equilibrium expressions of each country's consumer surplus are:

$$\widehat{\mathrm{CS}}(\hat{k}) = \frac{\left[1-e^{-iT(\hat{k})}\right]\left[\hat{x}_n\left(\underline{\mu}^*\right)\right]^2+e^{-iT(\hat{k})}\left[\hat{x}_n(\overline{\mu}^*)\right]^2}{2i}; \widehat{\mathrm{CS}}^*(\hat{k}) = \frac{\left[1-e^{-iT(\hat{k})}\right]\left[\hat{x}_s\left(\underline{\mu}^*\right)\right]^2+e^{-iT(\hat{k})}\left[\hat{x}_s(\overline{\mu}^*)\right]^2}{2i}$$

The Northern government benefits from public revenues from the Northern firm's patent expenditures. The Northern government's equilibrium discounted public revenues are:

$$\widehat{\mathrm{PR}}(\hat{k}) = \frac{\left[1-e^{-iT(\hat{k})}\right]\hat{k}}{i}$$

Under the initial case, the national welfares are: $\widehat{\mathrm{W}} = \widehat{\Pi} + \widehat{\mathrm{CS}} + \widehat{\mathrm{PR}}; \widehat{\mathrm{W}}^* = \widehat{\Pi}^* + \widehat{\mathrm{CS}}^*$.

3.5.2. Discussion

Let us study now the impact of each policy instrument on discounted sums of profit flows, consumer surplus and public revenues. Policy instruments may influence public revenues.[19] Table 3.1 illustrates the economic impact of each policy instrument.

-Table 3.1-

Economic Impact of Each Policy Instrument

Instrument	T	Π	Π^*	CS	CS*	PR	PR*
Production Subsidy (North)	+	+	–	+/–	+/–	+/–	0
Patent Subsidy (North)	+	+	–	–	–	+/–	0
Import Tariff (North)	+	+	–	–	–	+	0
Import Quota (North)	–	+	+/–	+/–	+	–	0
Production Subsidy (South)	–	–	+	+	+	–	–
Import Tariff (South)	–	–	+	+	–	–	+
Import Quota (South)	–	–	+	+	+/–	–	0
Public R&D (South)	–	–	+	+	+	–	–

Source: author.

The Northern government's production subsidy increases (reduces) the Northern (Southern) firm's discounted sum of profit flows by providing further revenues and by increasing the monopoly period with the new technology. There is a direct positive impact on each consumer surplus by increasing total supplies on each market and reducing each market price: $\mathrm{d}\hat{X}_n(\mu^*, s)/\mathrm{d}s = \mathrm{d}\hat{X}_s(\mu^*, s)/\mathrm{d}s = 1/3 > 0; \mathrm{d}\hat{p}_n(\mu^*, s)/\mathrm{d}s = \mathrm{d}\hat{p}_s(\mu^*, s)/\mathrm{d}s = -1/3 < 0$. But the total effect on each discounted consumer surplus is unknown because the production subsidy slows down the new technology diffusion. Finally, the production subsidy involves further public expenditures for the Northern government but it also increases patent expenditures. The total effect on the discounted public revenues is unknown.

The Northern government's patent subsidy increases (reduces) the Northern (Southern) firm's discounted sum of profit flows. The subsidy does not directly impact price and

[19] $$\widehat{\mathrm{PR}} = \begin{cases} \dfrac{\left[1-e^{-iT(\hat{k})}\right]\hat{k} - s\left\{\left[1-e^{-iT(\hat{k})}\right]\left[\hat{x}_n\left(\underline{\mu}^*\right)+\hat{x}_s\left(\underline{\mu}^*\right)\right]+\left[\hat{x}_n(\overline{\mu}^*)+\hat{x}_s(\overline{\mu}^*)\right]\right\}}{i}, \text{with the production subsidy } s \\ \dfrac{\left[1-e^{-iT(\hat{k})}-i\varphi\right]\hat{k}}{i}, \text{with the patent subsidy } \varphi \\ \dfrac{\left[1-e^{-iT(\hat{k})}\right]\hat{k} + t\left\{\left[1-e^{-iT(\hat{k})}\right]\hat{y}_n\left(\underline{\mu}^*\right)+\hat{y}_n(\overline{\mu}^*)\right\}}{i}, \text{with the tariff } t \end{cases}$$

$$\widehat{\mathrm{PR}}^* = \begin{cases} -s^* \dfrac{\left[1-e^{-iT(\hat{k})}\right]\left[\hat{y}_n\left(\underline{\mu}^*\right)+\hat{y}_s\left(\underline{\mu}^*\right)\right]+\left[\hat{y}_n(\overline{\mu}^*)+\hat{y}_s(\overline{\mu}^*)\right]}{i}, \text{with the production subsidy } s^* \\ t^* \dfrac{\left[1-e^{-iT(\hat{k})}\right]\hat{x}_s\left(\underline{\mu}^*\right)+\hat{x}_s(\overline{\mu}^*)}{i}, \text{with the tariff } t^* \\ -vr^*, \text{with the public Research and Development investment } r^* \end{cases}$$

outputs. But the Southern firm uses the old technology for longer i.e. its marginal cost remains $c^*\left(\underline{\mu}^*\right)$ for longer. Therefore, it reduces each country's consumer surplus. The effect on the Northern country's public revenues is uncertain because there is a negative effect via public expenditures and a positive effect via the increase in patent expenditures.

The Northern government's import tariff reduces (increases) the Southern (Northern) firm's discounted sum of profit flows due to further transport costs. It also reduces the Northern country's consumer surplus by reducing the total supplies and increasing the market price: $\mathrm{d}\hat{X}_n(\mu^*, t)/\mathrm{d}t = -1/3 < 0; \mathrm{d}\hat{p}_n(\mu^*, t)/\mathrm{d}t = 1/3 > 0$. The tariff also reduces the Southern country's consumer surplus by increasing the monopoly period with the new technology. Finally, the Northern government's tariff leads to further public revenues for the Northern country.

The Northern government's import quota accelerates the new technology diffusion by reducing the monopoly period with the new technology. The quota increases the Northern firm's discounted sum of profit flows. The effect on the Southern firm's discounted profit is unknown because it reduces its exports and accelerates the new technology diffusion. The effect on the Northern country's discounted consumer surplus is unknown for the same reason. The quota increases the Southern country's discounted consumer surplus by reducing the monopoly period with the new technology. Finally, it reduces the Northern government's public revenues by reducing patent expenditures.

The Southern government's production subsidy and import tariff reduce (increase) the Northern (Southern) firm's discounted sum of profit flows. The Southern government's production subsidy (tariff) has an unknown effect on (reduces) each (the Southern) country's consumer surplus and involves further public expenditures (revenues) for the Southern government. The Southern government's tariff increases the Northern country's consumer surplus by reducing the monopoly period. But it reduces the Northern government's public revenues by reducing patent expenditures.

The Southern government's import quota accelerates the new technology diffusion by reducing the monopoly period. It reduces (increases) the Northern (Southern) firm's discounted sum of profit flows. It increases the Northern country's discounted consumer surplus by accelerating the new technology diffusion. But the effect on the Southern country's consumer surplus is uncertain because it also reduces the Northern firm's exports.

The Southern government's public R&D investment increases the Southern firm's discounted sum of profit flows by providing an intermediate technology over $[0, T)$. The Northern firm's discounted sum of profit flows decreases as compared to the initial case without R&D owing to the rise in the Southern firm's domestic sales and exports. Furthermore, the Northern firm reduces its patent expenditures. The effect on each country's consumer surplus is positive. But it involves further public expenditures for the Southern government and reduces the Northern government's public revenues.

3.5.3. Optimal Policy Instruments under Numerical Simulations

According to the economic impact of each policy instrument, we have to verify whether or not governments are encouraged to implement it. Let us study the impact on national welfares W and W*. We can also compare each instrument.

Table 3.2 illustrates the optimal level of each instrument and the effect on national welfares as compared to the initial case, when the foreign government does not implement policy instruments. The results are obtained under numerical simulations because analytical demonstrations seem complex. We consider that the Northern firm's marginal cost is lower (higher) than the Southern firm's marginal cost when it uses the old (new) technology. We set: $c(\overline{\mu}) = 6; c^*\left(\underline{\mu}^*\right) = 9; c^*\left(\overline{\mu}^*\right) = 3$. When each firm uses the new technology, the Southern firm's marginal cost is lower because it benefits from a lower labor cost. Since we consider a linear function for the monopoly period, we set: $\theta = 5; \omega = 1$. Finally, we consider that the nominal interest rate equals one percent because such a value relates to the current low level of interest rates: $i = 0.01$.

-Table 3.2-

Optimal Policy Instruments

Instrument	Optimal Value	ΔW	ΔW*
Production Subsidy (North)	23.8612717	22151.2878	-1865.90818
Patent Subsidy (North)	0.9999	43.5021429	-243.482143
Import Tariff (North)	13.3515851	8917.4674	-13534.7484
Import Quota (North)	0	7743.50649	-14320.069
Production Subsidy (South)	18.9035745	-7609.00861	13553.846
Import Tariff (South)	11.1251021	-11781.9601	6148.17801
Import Quota (South)	0	-13570.938	4135.66017
Public R&D (South)	52.2290503	-4394.43969	24000.7106

Source: author.

Note: $a_n = 50; a_s = 40; c(\overline{\mu}) = 6; c^*\left(\underline{\mu}^*\right) = 9; c^*\left(\overline{\mu}^*\right) = 3; g = g^* = 1; \theta = 5; \omega = 1; i = 0.01$. For the Southern government's public R&D expenditures, we use a linear marginal cost function: $c^*[\mu^*_{r^*}(r^*)] = c^*\left(\overline{\mu}^*\right) + \lambda/(1 + r^*)$, with $\lambda = 6$. The unit cost of the public R&D equals: $v^* = 10$.

We conclude that:

- The Northern government is encouraged to implement a production subsidy and an import tariff because their optimal levels are positive. They increase the Northern country's national welfare. The Northern government's tariff always reduces the Southern country's national welfare. But the Northern government's production subsidy may increase the Southern country's national welfare. The potential positive effect on the consumer surplus may be stronger than the negative effect on the discounted sum of profit flows. Nevertheless, the production subsidy s often reduces the Southern country's national welfare.
- The Southern government is also encouraged to implement a production subsidy and an import tariff for the same reason. They increase (reduce) the Southern (Northern) country's national welfare. We do not find any case in which the Southern government's production subsidy increases the Northern country's national welfare.

- The Northern government is encouraged to subsidize its domestic firm's patent expenditures because the optimal patent subsidy is positive. The optimal patent subsidy tends towards one under each case.
- The Southern government is encouraged to implement a public R&D program because the optimal level of public R&D is positive. It increases (reduces) the Southern (Northern) country's national welfare.
- Each government is encouraged to implement a prohibitive quota such as the foreign firm no longer exports to the domestic market. With a relatively binding import quota implemented by the Northern government, the Southern country's discounted national welfare may increase as compared to the initial case. Therefore, the Southern government may be encouraged to implement a VER.
- The Northern country's favorite policy instrument is the production subsidy. We have: $s \succ t \succ q \succ \varphi$, where $\succ$ denotes the Northern government's preference. The reasons are: (i) the production subsidy is the only policy instrument that can increase the Northern discounted profit, the Northern discounted consumer surplus and the Northern discounted public revenues (if patent expenditures sharply increase compared to the initial case); (ii) it directly increases the Northern firm's profit via further revenues compared to a tariff and a quota that only reduce competition from the South; (iii) it may increase the domestic discounted consumer surplus unlike the patent subsidy.
- The Southern country's favorite policy instrument is the public R&D investment. We have: $r^* \succ s^* \succ t^* \succ q^*$. The public R&D increases the Southern firm's discounted profit by providing an intermediate technology over $[0, T)$. The difference with respect to the production subsidy is that the Southern government only incurs the R&D cost at period 0.

The results generally hold when the value of parameters varies (see Appendix 3.B). But the Southern government's favorite policy instrument becomes the production subsidy under one case: when the value of $c^*\left(\underline{\mu}^*\right)$ decreases. In this case, the cost of the technological gap is lower for the Southern firm. A production subsidy leads to a higher increase in its expected profit.

3.6. Second Extension: A Licensing Contract

Consider now the case of a licensing contract i.e. a financial transfer (royalty) from the Southern firm to the Northern firm in order to buy the intellectual property right. In this case, the Southern firm benefits from the new technology $\overline{\mu}^*$ at the date of the licensing contract. Modeling such a contract is realistic since patent licensing *"is quite widespread and takes place in almost industries* [**Filippini, 2005**, p. 582]*."*

3.6.1. General Framework with the License

Patent licensing contracts are generally royalties per unit of output produced with the patented technology. However, we only consider that royalties are paid at the period of the licensing contract in order to simplify the demonstration. Since our structure is a duopoly, we consider that maintenance fees with the patent for the Northern firm are removed after the licensing contract.

The licensing contract is implemented at the date L over $[0, T)$. Of course, we have: $L < T(\theta)$. There is no economic impact, otherwise. The Southern firm benefits from the new technology $\overline{\mu}^*$ over $[L, \infty)$. The license involves a financial transfer from the Southern firm to the Northern firm. This is the price of licensing. As a consequence, there is a further cost for the Southern firm denoted by λ. Such a cost depends on the date L. The license is costlier when L is lower.

Assumption 3.7: The Southern firm's cost of licensing λ is a decreasing function of L: $\lambda = \lambda(L)$, with $\lambda'(L) < 0$.

The discounted sums of profit flows are the following:

$$\Pi(L) = \int_0^L e^{-i\tau}\left[\hat{\pi}\left(\underline{\mu}^*\right) - k\right]\mathrm{d}\tau + \int_L^\infty e^{-i\tau}\hat{\pi}\left(\overline{\mu}^*\right)\mathrm{d}\tau + e^{-iL}\lambda(L) \tag{3.9}$$

$$\Pi^*(L) = \int_0^L e^{-i\tau}\hat{\pi}^*\left(\underline{\mu}^*\right)\mathrm{d}\tau + \int_L^\infty e^{-i\tau}\hat{\pi}^*\left(\overline{\mu}^*\right)\mathrm{d}\tau - e^{-iL}\lambda(L) \tag{3.10}$$

Integrating these expressions, we have:

$$\Pi(L) = \frac{\left(1-e^{-iL}\right)\left[\hat{\pi}\left(\underline{\mu}^*\right)-k\right]+e^{-iL}\left[\hat{\pi}\left(\overline{\mu}^*\right)+i\lambda(L)\right]}{i};\ \Pi^*(L) = \frac{\left(1-e^{-iL}\right)\hat{\pi}^*\left(\underline{\mu}^*\right)+e^{-iL}\left[\hat{\pi}^*\left(\overline{\mu}^*\right)-i\lambda(L)\right]}{i} \tag{3.11}$$

The Southern firm selects the optimal date of the license that maximizes its discounted sum of profit flows. The first order condition leads to:

$$i\lambda(L) - \lambda'(L) = \hat{\pi}^*\left(\overline{\mu}^*\right) - \hat{\pi}^*\left(\underline{\mu}^*\right) \tag{3.12}$$

We set a function for the cost of licensing: $\lambda(L) = \delta - L$. In this case, the first order condition gives:

$$\hat{L} = \frac{i\delta+1-\left[\hat{\pi}^*\left(\overline{\mu}^*\right)-\hat{\pi}^*\left(\underline{\mu}^*\right)\right]}{i} \tag{3.13}$$

where $\hat{L}$ denotes the optimal date of the licensing contract for the Southern firm and $i\delta + 1 > \left[\hat{\pi}^*\left(\overline{\mu}^*\right) - \hat{\pi}^*\left(\underline{\mu}^*\right)\right]$. The second order condition is verified because the second derivative is given by:

$$\frac{\partial^2\Pi}{\partial L^2} = i^2 e^{-iL}\left[\hat{\pi}^*\left(\overline{\mu}^*\right) - \hat{\pi}^*\left(\underline{\mu}^*\right) - i(\delta - L) - 2\right] < 0.$$

The condition is that:

$$\hat{L} < \frac{\left\{i\delta+2-\left[\hat{\pi}^*\left(\overline{\mu}^*\right)-\hat{\pi}^*\left(\underline{\mu}^*\right)\right]\right\}}{i}$$

Equation (3.13) satisfies such a condition.

An interpretation of (3.13) stems for rewriting as: $L = \psi\left[\hat{\pi}^*\left(\overline{\mu}^*\right) - \hat{\pi}^*\left(\underline{\mu}^*\right)\right]$. The date of licensing depends on the Southern firm's difference in profit $\left[\hat{\pi}^*\left(\overline{\mu}^*\right) - \hat{\pi}^*\left(\underline{\mu}^*\right)\right]$ and is a decreasing function: $\partial\psi/\partial\left[\hat{\pi}^*\left(\overline{\mu}^*\right) - \hat{\pi}^*\left(\underline{\mu}^*\right)\right] < 0$. We have:

$$\hat{\pi}^*\left(\overline{\mu}^*\right) - \hat{\pi}^*\left(\underline{\mu}^*\right) = \frac{4\left[c^*\left(\underline{\mu}^*\right)-c^*\left(\overline{\mu}^*\right)\right]\left[a_n+a_s+2c(\overline{\mu})-2c^*\left(\underline{\mu}^*\right)-2c^*\left(\overline{\mu}^*\right)+g-2g^*\right]}{9} \tag{3.14}$$

The Northern firm sells its property right only if a profit gain appears. The condition is that its discounted sum of profit flows is higher with the license compared to that without the license. The Northern firm accepts the licensing contract only if: $\Pi(\hat{L}) > \Pi(\hat{k})$. The date of the license L must be greater than the threshold $\overline{L}$ such as $\Pi(\overline{L}) = \Pi(k)$. We have:

$$\overline{L} = \delta - \frac{\left\{1-e^{-i[T(k)-\overline{L}]}\right\}\left[\pi\left(\underline{\mu}^*\right)-k-\pi\left(\overline{\mu}^*\right)\right]}{i} \tag{3.15}$$

Since both sides of (3.15) depends on $\overline{L}$, it seems complex to find the value of $\overline{L}$. The Northern firm sells the intellectual property right at the period $\hat{L}$ if $\hat{L} > \overline{L}$. The patent is maintained in force until $T(k)$, otherwise. We make the assumption that $\hat{L} > \overline{L}$. The Southern firm cannot select the optimal date of license, otherwise.

Assumption 3.8: The licensing contract is implemented: $\hat{L} > \overline{L}$.

3.6.2. The Impact of Import Tariffs and Production Subsidies

Proposition 3.6: The implementation of an import tariff and a production subsidy by the Northern (Southern) government increases (reduces) the level of $\hat{L}$ and slows down (accelerates) the new technology diffusion as compared to free trade. A tariff (subsidy) war slows down (accelerates) the new technology diffusion.

Proof: □

- First, let us study the impact of tariffs. We focus on the Southern firm's difference in profit that depends on each tariff. We have:
  $$\frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,t)-\hat{\pi}^*\left(\underline{\mu}^*,t\right)\right]}{\mathrm{d}t} = -\frac{8\left[c^*\left(\underline{\mu}^*\right)-c^*(\overline{\mu}^*)\right]}{9} < 0$$
  $$\frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,t)-\hat{\pi}^*\left(\underline{\mu}^*,t\right)\right]}{\mathrm{d}t^*} = \frac{4\left[c^*\left(\underline{\mu}^*\right)-c^*(\overline{\mu}^*)\right]}{9} > 0$$
  $$\frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,t,t^*)-\hat{\pi}^*\left(\underline{\mu}^*,t,t^*\right)\right]}{\mathrm{d}t} + \frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,t,t^*)-\hat{\pi}^*\left(\underline{\mu}^*,t,t^*\right)\right]}{\mathrm{d}t^*} = -\frac{4\left[c^*\left(\underline{\mu}^*\right)-c^*(\overline{\mu}^*)\right]}{9} < 0$$
  The implementation of the Northern (Southern) government's import tariff reduces (increases) the Southern firm's difference in profit. The level of $\hat{L}$ is higher (lower) as compared to free trade. It slows down (accelerates) the new technology diffusion as compared to free trade. Finally, a tariff war slows down the new technology diffusion by reducing the difference in profit and increasing $\hat{L}$.
- Now, let us study the impact of production subsidies. We have:
  $$\frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,s)-\hat{\pi}^*\left(\underline{\mu}^*,s\right)\right]}{\mathrm{d}s} = -\frac{8\left[c^*\left(\underline{\mu}^*\right)-c^*(\overline{\mu}^*)\right]}{9} < 0$$
  $$\frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,s^*)-\hat{\pi}^*\left(\underline{\mu}^*,s^*\right)\right]}{\mathrm{d}s^*} = \frac{16\left[c^*\left(\underline{\mu}^*\right)-c^*(\overline{\mu}^*)\right]}{9} > 0$$
  $$\frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,s,s^*)-\hat{\pi}^*\left(\underline{\mu}^*,s,s^*\right)\right]}{\mathrm{d}s} + \frac{\mathrm{d}\left[\hat{\pi}^*(\overline{\mu}^*,s,s^*)-\hat{\pi}^*\left(\underline{\mu}^*,s,s^*\right)\right]}{\mathrm{d}s^*} = \frac{8\left[c^*\left(\underline{\mu}^*\right)-c^*(\overline{\mu}^*)\right]}{9} > 0$$
  An implementation of a production subsidy by the Northern (Southern) government reduces (increases) the Southern firm's difference in profit and slows down

(accelerate) the new technology diffusion by increasing (reducing) the level of L. The total impact of both subsidies on the difference in profit is positive. A subsidy war accelerates the new technology diffusion.

The results show that the impact of each policy instrument is the same compared to previous sections. But now, a tariff war slows down the new technology diffusion while a subsidy war accelerates it. The reason is that the speed of the new technology diffusion now depends on the Southern firm's behavior through the licensing contract. □

3.6.3. The impact of Import Quotas

Proposition 3.7: The implementation of an import quota by the Northern firm always slows down the new technology diffusion by increasing the level of $\hat{L}$. A relatively binding quota implemented by the Southern government slows down the new technology diffusion. With a strongly binding quota, there is a threshold $\overline{q}^*$ such as the date of the licensing contract equals the free trade level. The quota accelerates (slows down) the new technology diffusion with a more (less) binding quota.

Proof: □

- Let us study the impact of an import quota q implemented by the Northern government. We consider the two previous cases again: a relatively binding quota and a strongly binding quota:
  - First case: $\hat{y}_n\left(\underline{\mu}^*\right) \leq q < \hat{y}_n(\overline{\mu}^*)$. The quota is relatively binding. The quota is binding only after the new technology diffusion. In this case, the Southern firm's difference in profit $\left[\hat{\pi}^*(\overline{\mu}^*, q) - \hat{\pi}^*\left(\underline{\mu}^*, q\right)\right]$ decreases as compared to free trade. The Southern firm increases the date of the license $\hat{L}$.
  - Second case: $q < \hat{y}_n\left(\underline{\mu}^*\right)$. The quota is strongly binding. The Southern firm's profit decreases regardless of the Southern firm's technological endowment. We denote by $\hat{\pi}_n^*$ the Southern firm's profit on the Northern market. The Southern firm's difference in profit on the Northern market now equals:
    $\left[\hat{\pi}_n^*(\overline{\mu}^*, q) - \hat{\pi}_n^*\left(\underline{\mu}^*, q\right)\right] = q\left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]$
    Under free trade, we have:
    $\left[\hat{\pi}_n^*(\overline{\mu}^*) - \hat{\pi}_n^*\left(\underline{\mu}^*\right)\right] = \frac{2\left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]\left[\hat{y}_n\left(\underline{\mu}^*\right) + \hat{y}_n(\overline{\mu}^*)\right]}{3}$
    We have to compare these expressions. Note that we have: $2\left[\hat{y}_n\left(\underline{\mu}^*\right) + \hat{y}_n(\overline{\mu}^*)\right]/3 = \hat{y}_n\left(\underline{\mu}^*\right) + \left[2\hat{y}_n(\overline{\mu}^*) - \hat{y}_n\left(\underline{\mu}^*\right)\right]/3 > q$, because $\hat{y}_n\left(\underline{\mu}^*\right) > q$. The difference in profit decreases as compared to free trade. The Southern firm increases $\hat{L}$.
- Now let us study the impact of an import quota q^* implemented by the Southern government. We consider two cases again:
  - First case: $\hat{x}_s(\overline{\mu}^*) \leq q^* < \hat{x}_s\left(\underline{\mu}^*\right)$. The quota is relatively binding. The quota is binding only before the new technology diffusion. In this case, the Southern firm's

difference in profit $\left[\hat{\pi}^*(\overline{\mu}^*, q^*) - \hat{\pi}^*\left(\underline{\mu}^*, q^*\right)\right]$ decreases as compared to free trade. The Southern firm increases the date of the license $\hat{L}$.

- Second case: $q^* < \hat{x}_S(\overline{\mu}^*)$. The quota is strongly binding. We denote by $\hat{\pi}_S^*$ the Southern firm's profit on the Southern market. We have:
$\left[\hat{\pi}_S^*(\overline{\mu}^*, q^*) - \hat{\pi}_S^*\left(\underline{\mu}^*, q^*\right)\right] = \frac{\left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]\left[\hat{y}_S\left(\underline{\mu}^*, q^*\right) + \hat{y}_S(\overline{\mu}^*, q^*)\right]}{2}$
Under free trade, we have:
$\left[\hat{\pi}_S^*(\overline{\mu}^*) - \hat{\pi}_S^*\left(\underline{\mu}^*\right)\right] = \frac{2\left[c^*\left(\underline{\mu}^*\right) - c^*(\overline{\mu}^*)\right]\left[\hat{y}_S\left(\underline{\mu}^*\right) + \hat{y}_S(\overline{\mu}^*)\right]}{3}$
We find the condition such as the difference in profit increases with the quota as compared to free trade: $q^* < \overline{q}^*$, with:
$\overline{q}^* = \frac{2a_S - 8c(\overline{\mu}) + 7c^*\left(\underline{\mu}^*\right) + 7c^*(\overline{\mu}^*)}{18}$
where $\overline{q}^*$ denotes the level of quota such as the Southern firm's difference in profit equals the free trade level. We can easily demonstrate that $\overline{q}^*$ is over $\left(0, \hat{x}_S(\overline{\mu}^*)\right)$. The difference in profit decreases as compared to free trade when $q^* \in \left(\overline{q}^*, \hat{x}_S(\overline{\mu}^*)\right)$, levels off when $q^* = \overline{q}^*$, and increases when $q^* \in \left[0, \overline{q}^*\right)$.

The impact of each quota is reversed compared to the previous results. Now, the Northern government's quota always slows down the new technology diffusion. Both a relatively binding and a strongly binding quota slow down the new technology diffusion. Such a result means that a VER implemented by the Southern country no longer accelerates the new technology diffusion. The Southern government's quota either slows down or accelerates the new technology diffusion. A strongly binding quota accelerates the new technology diffusion only if $q^* \in \left[0, \overline{q}^*\right)$. □

3.7. Concluding Remarks

The objective of this chapter is to study the impact of policy instruments on technology diffusion in a dynamic North-South model. Here, we have explored a case in which the Northern firm implements a patent in order to increase the monopoly period with the new technology. Then, we have demonstrated that developing countries can accelerate technology diffusion by implementing policy instruments. However, developed countries can slow it down in exactly the same way, except for an import quota. Now, if developed countries aim to help developing countries by accelerating technology diffusion, liberalization is one way to do it. In this way, the role of the WTO via a TRIPs agreement and trade liberalization is crucial to promote access to technological information for developing countries.

It seems complex to find empirical examples to explain why the Southern government's policy instruments generally reduce the Northern firm's patent length. Empirically, there is a positive correlation between the probability that an innovator maintains a patent in force and the return to such a patent (**Pakes, 1986**). The return is the profit gain. Furthermore, policy instruments involve profit-shifting among firms. The Southern government's policy instruments increase (reduce) the Southern (Northern) firm's profit. These previous results hold both theoretically and empirically.

A possible example is climate-friendly green technologies (**Deutsche Bank Research, 2010**). Innovators from developed countries file patents on green technologies that slow down the green technologies diffusion to developing countries. *"At the United Nations Climate Change Conference 2009 in Copenhagen, a group of 77 developing countries and emerging markets … called for an end to patent protection in general or compulsory licensing … for climate-friendly and/or energy-efficient technologies in order to speed up the growth-enhancing transfer of technology* [**Deutsche Bank Research, 2010**, p. 1]*."* The report introduces the option that funds should be granted to poor countries in order to use green technologies at an earlier date. Such an example relates to the profit-shifting with the implementation of policy instruments like production subsidies for Southern firms. In this case, it accelerates the new technology diffusion.

An important result is the impact of the Northern government's quota on the speed of the new technology diffusion. Both a relatively binding and a strongly binding quota accelerate the diffusion as compared to the initial case while other policy instruments slow it down. The result relates to the fact that trade restrictions may reduce the incentive to innovate (see Chapters 1 and 2). Such a result means that the Southern government could be encouraged to implement Voluntary Export Restraints in order to accelerate the new technology diffusion. Furthermore, such a VER may increase the Southern country's discounted national welfare.

Here, we omit externalities of technology diffusion in developing countries in the welfare analysis in order to study a simple case. At points, negative externalities appear. For example, there is a cost for unskilled labor. Modern technologies require that firms in developing countries hire skilled labor. Another example is the environment. Technology diffusion may create pollution in developing countries.

Appendix to Chapter 3

3.A. General Forms for Inverse Demand Functions

Using general forms, we consider that the static second order conditions are verified: $\pi_{x_i x_i} < 0; \pi^*_{y_i y_i} < 0$. Cross effects are also negative: $\pi_{x_i y_i} < 0; \pi^*_{y_i x_i} < 0$. Own effects are stronger than cross effects: $|\pi_{x_i x_i}| > |\pi_{x_i y_i}|; |\pi^*_{y_i y_i}| > |\pi^*_{y_i x_i}|$. Stability conditions are verified on each market: $D_i = \pi_{x_i x_i}\pi^*_{y_i y_i} - \pi_{x_i y_i}\pi^*_{y_i x_i} > 0$. We have:

$$\frac{\mathrm{d}\hat{\pi}}{\mathrm{d}s} = \frac{\hat{x}_n \pi_{x_n x_n} \pi^*_{y_n y_n}}{D_n} + \frac{\hat{x}_s \pi_{x_s x_s} \pi^*_{y_s y_s}}{D_s} > 0$$

$$\frac{\mathrm{d}\hat{\pi}}{\mathrm{d}s^*} = -\left(\frac{\hat{x}_n \pi_{x_n x_n} \pi_{x_n y_n}}{D_n} + \frac{\hat{x}_s \pi_{x_s x_s} \pi_{x_s y_s}}{D_s}\right) < 0$$

$$\frac{\mathrm{d}\hat{\pi}}{\mathrm{d}t} = \frac{\hat{x}_n \pi_{x_n x_n} \pi_{x_n y_n}}{D_n} > 0$$

$$\frac{\mathrm{d}\hat{\pi}}{\mathrm{d}t^*} = -\frac{\hat{x}_s \pi_{x_s x_s} \pi^*_{y_s y_s}}{D_s} < 0$$

Under linear demand function, the only terms that depend on μ^* are $\hat{x}_n$ and $\hat{x}_s$. We have already proven that the Northern firm's domestic sales and exports increase with the Southern firm's marginal cost. The positive (negative) effect of s and t (s^* and t^*) on π is stronger when the Southern firm uses the old technology $\mu^* = \underline{\mu}^*$. The production subsidy and the tariff implemented by the Northern (Southern) government increase (reduce) the difference in profit. But under nonlinear demand function, it is complex to find general results because each term depends on μ^*. In this case, each instrument may increase or decrease the difference in profit. Nevertheless, we did not find any nonlinear example in which the effects of s and t (s^* and t^*) are negative (positive). Therefore, the tariff and the production subsidy implemented by the Northern (Southern) government generally slow down (accelerate) the new technology diffusion.

3.B. Numerical Simulations for the Welfare Analysis

-Table 3.3-

Optimal Policy Instruments When Parameters Vary

	Policy Instrument	Optimal Value	ΔW	ΔW*
$\Delta a_s = 10$	Production Subsidy (North)	25.290453	24884.446	-960.921509
	Patent Subsidy (North)	0.9999	49.995	-249.975
	Import Tariff (North)	13.3506118	8915.48189	-13525.7287
	Import Quota (North)	0	7750	-14332.1429
	Production Subsidy (South)	23.2244619	-11646.5167	20483.7046
	Import Tariff (South)	14.462308	-19603.7866	10395.9037
	Import Quota (South)	0	-22453.3333	7204.16667
	Public R&D (South)	55.8629685	-5709.82651	27921.6878
$\Delta a_s = 20$	Production Subsidy (North)	26.7194045	27775.5342	57.43592
	Patent Subsidy (North)	0.9999	55.1491237	-255.129124
	Import Tariff (North)	13.3496751	8913.69435	-13518.1238
	Import Quota (North)	0	7755.15464	-14340.7316
	Production Subsidy (South)	27.5395673	-16569.5534	28838.1571
	Import Tariff (South)	17.7979499	-29401.5686	15752.6067
	Import Quota (South)	0	-33559.2898	11107.3454

	Public R&D (South)	59.2784275	-7026.78422	31848.3402
$\Delta c^*\left(\underline{\mu}^*\right) = -3$	Production Subsidy (North)	23.4323182	21361.5118	-7599.31365
	Patent Subsidy (North)	0.9999	40.1986824	-270.581047
	Import Tariff (North)	14.3513642	10303.1016	-17744.2922
	Import Quota (North)	0	7990.2027	-19509.1327
	Production Subsidy (South)	21.3387132	-3420.48458	16973.2693
	Import Tariff (South)	11.1498359	-10306.4705	6165.59765
	Import Quota (South)	0	-11335.8509	5011.71948
	Public R&D (South)	52.2290468	-1914.41015	12323.609
$\Delta c^*\left(\underline{\mu}^*\right) = 3$	Production Subsidy (North)	22.9999	22890.4317	3030.72601
	Patent Subsidy (North)	0.9999	46.5578438	-218.415656
	Import Tariff (North)	12.3517705	7631.8282	-9771.01994
	Import Quota (North)	0	7196.5625	-9929.63153
	Production Subsidy (South)	16.6085162	-10631.1635	10554.0823
	Import Tariff (South)	11.1046478	-13253.3932	6133.39921
	Import Quota (South)	0	-16005.9465	3035.19153
	Public R&D (South)	52.2290468	-7374.71702	33975.7796
$\Delta c(\overline{\mu}) = -3$	Production Subsidy (North)	25.9999	26308.7934	3890.04012
	Patent Subsidy (North)	0.9999	49.4332584	-198.856517
	Import Tariff (North)	13.350277	8914.88868	-11737.1933
	Import Quota (North)	0	8336.9382	-12038.3501
	Production Subsidy (South)	18.2693175	-12004.0347	12822.7549
	Import Tariff (South)	12.0842229	-15511.1376	7273.78412
	Import Quota (South)	0	-18640.1043	3766.56477
	Public R&D (South) (a)	50.8817373	-5767.14252	22616.2001
$\Delta c(\overline{\mu}) = 3$	Production Subsidy (North)	21.717602	18349.5976	-6668.62659
	Patent Subsidy (North)	0.9999	35.3810769	-304.584923
	Import Tariff (North)	13.3529608	8920.46299	-15340.6992
	Import Quota (North)	0	6922.88462	-16789.2308
	Production Subsidy (South)	20.0074228	-2643.29956	14465.1641
	Import Tariff (South)	10.1990618	-8492.75698	5137.33085
	Import Quota (South)	0	-9301.36752	4207.88462
	Public R&D (South) (a)	53.5497695	-3019.515	25392.0572
$\Delta\omega = -0.5$	Production Subsidy (North)	23.8653991	22168.45	-2046.69722
	Patent Subsidy (North)	0.9999	87.0042857	-486.964286
	Import Tariff (North)	13.369823	8946.07921	-13637.584
	Import Quota (North)	0	7687.01299	-14240.138
	Production Subsidy (South)	19.431957	-7686.79813	13919.0691
	Import Tariff (South)	11.252551	-11829.756	6247.93573
	Import Quota (South)	0	-13530.7648	4333.82035
	Public R&D (South)	44.1092	-4375.88165	24041.2713
$\Delta\omega = 1$	Production Subsidy (North)	23.8592075	22142.7072	-1775.52426
	Patent Subsidy (North)	0.9999	21.7510714	-121.741071
	Import Tariff (North)	13.3424613	8903.17398	-13483.4004
	Import Quota (North)	0	7771.75325	-14360.0345
	Production Subsidy (South)	18.6602839	-7521.45641	13378.3546
	Import Tariff (South)	11.062265	-11757.7479	6098.89427
	Import Quota (South)	0	-13591.0245	4036.58009
	Public R&D (South)	52.2002932	-4397.77749	23973.0386

Source: author.

Note: $a_n = 50; a_s = 40; c(\overline{\mu}) = 6; c^*\left(\underline{\mu}^*\right) = 9; c^*(\overline{\mu}^*) = 3; g = g^* = 1; \theta = 5; \omega = 1; i = 0.1; v^* = 10;\ \lambda = 6.$ (a) Since the Southern firm's marginal cost depends on the public R&D investment, we study the case in which the parameter λ varies.

-CHAPTER 4-

Technology Diffusion via Patent Collaborations: the Case of the European Union Integration[20]

4.1. Introduction

There is a growing interest for the study of international patent collaborations as a potential measure for technology diffusion in the economic literature. They can be defined as patents filed by domestic applicants with co-inventors located in foreign countries. The total number of patent collaborations dramatically increased from 24,194 in 1980 to 137,120 in 2012 (source: OECD).

The economic literature has already studied the impact of potential determinants of patent collaborations (see the review of the economic literature on patent collaborations in Chapter 0, at the end of subsection 0.4.3). Therefore, it would be interesting to make an original contribution for a specific region of the world, for instance the European Union.

This chapter studies the impact of potential determinants of technology diffusion in an empirical framework. The explained variable is patent collaborations between developed and emerging countries. The applicant is located in the emerging country while the foreign co-inventor is located in the developed country. They have to pay a patent filing cost that depends on the patent length. In this case, co-inventors benefit from an industrial protection on the market of the country where they filed the patent.

Several variables may be significant determinants of both the probability and the intensity of patent collaborations. First, we run Logit estimations by studying their impact on the probability of collaborations. Then, we run both conditional and total estimations by studying their impact on the intensity. With conditional estimations, we only integrate the cases in which the number of collaborations at least equals one and we run both OLS/GLS and Poisson estimations. With total estimations, we integrate all the cases and we only run Poisson estimations.

The example of the European Union (EU) is illustrated here. We use data for Eastern and Western European countries over the period 2000-2011. In this chapter, we denote countries of the former "Eastern Bloc" as European emerging countries and Western European countries as European developed countries. We consider patent collaborations between these two groups of countries i.e. the number of patents filed at the European Patent Office (EPO) by an inventor located in a European emerging country with a foreign co-inventor located in a European developed country. Inventors from non EU

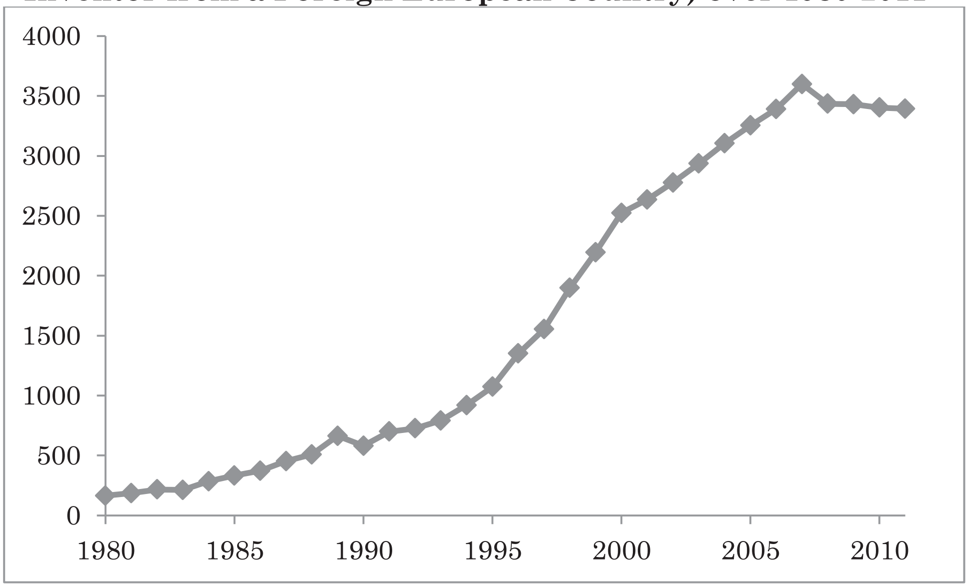
[20] This chapter has been published in a *LAREFI Working Paper* (**Berthoumieu, 2015**).

countries can file patents at the EPO.[21] Then, inventors benefit from an industrial protection on the European market.

There is a growing interest in patent collaborations in the European Union (see Figure 4.1). Technological collaborations represent a way to benefit from foreign sources of productivity in Europe, especially for Eastern transition economies.

-Figure 4.1-

Evolution of the Number of Patent Collaborations (Priority Date) Filed at the European Patent Office by an Inventor from the European Union (with a Co-Inventor from a Foreign European Country) over 1980-2011[22]



Source: OECD.

The main issue of this chapter is to study the impact of the European Union integration of Eastern European countries on their patent collaborations with Western European countries. The European integration is measured by a dummy equal to one when the emerging country is a European Union member and zero, otherwise. Here, the European integration relates to: (i) a customs union in which trade barriers are removed and countries set common external import tariffs; (ii) an internal market with the free movements of goods, capital, services and people.

Picci (2010) studies the impact of a dummy variable for EU members on the number of internationalized patents and generally finds a positive impact, except for one case in which the coefficient is significantly negative. **Cappelli and Montobbio (2016)** also find a positive impact of the European Union integration on patent collaborations over 1981-2000. Nevertheless, the author uses a general structure for 56 countries. He does not focus on technological relationships between developed and emerging countries.

[21] For example, Russian inventors file patents at the EPO while Russia is not an EU member, neither an EPO member.

[22] The priority date is the filing date of the very first application for a specific invention (source: EPO, WIPO).

In this chapter, we focus on collaborations between European developed and emerging countries. Furthermore, we aim to study the impact of transition economies' European integration on both the probability and the intensity of patent collaborations with developed countries while the economic literature has essentially focused on the intensity. These two points are the main contributions of our chapter.

Previous studies have analyzed trade agreements as an endogenous variable. **Baier and Bergstrand (2004)** show that the probability of a free trade agreement between two countries is higher: (i) the closer in economic and geographic distance are these countries; (ii) the more remote they are from the rest of the world; (iii) when each national income increases; (iv) when the difference in terms of labor-capital endowments between the two countries is high; (v) when such a difference is low with respect to the rest of the world. Here, we focus on the impact of the European Union integration as an exogenous variable. We implement tests in order to verify that there is no endogeneity problem.

We also study the impact of gravity equation variables like common borders, geographic distance, populations and Gross Domestic Product (GDP). Then, we analyze the impact of each country's R&D expenditures and of public expenditures on education. These two variables are potential measures of investments in human capital. We also analyze the impact of the technological gap and of the technological distance between Eastern and Western European countries. We define technological gap as a difference in the level of innovations while technological distance is a difference in the structure of innovations. Finally, we study the impact of imports, exports and FDI.

The results illustrate a positive and significant impact of the European integration on the intensity of patent collaborations under both conditional and total estimations while the impact on the probability of patent collaborations under Logit regressions is not significant. The most significant determinant (of both the number and the probability of patent collaborations) is emerging countries' exports to developed countries. However, the impact of imports and FDI is not significant.

Several variables are also positive determinants of the probability and/or the intensity of patent collaborations: populations, common borders, emerging countries' GDP, emerging countries' R&D and emerging countries' public expenditures in education. Other variables may have a negative impact: geographic distance, income inequalities, technological gap and technological distance.

Section 4.2 introduces the general framework of the chapter. Section 4.3 presents the database. Section 4.4 presents the results of Logit estimations with the probability of patent collaborations as the explained variable. Section 4.5 presents the results of both conditional and total estimations with the number of patent collaborations. Section 4.6 summarizes and discusses the results. Section 4.7 assesses the robustness of the results by using the number of years from the European integration to the last year of the database instead of a dummy variable. Section 4.8 concludes.

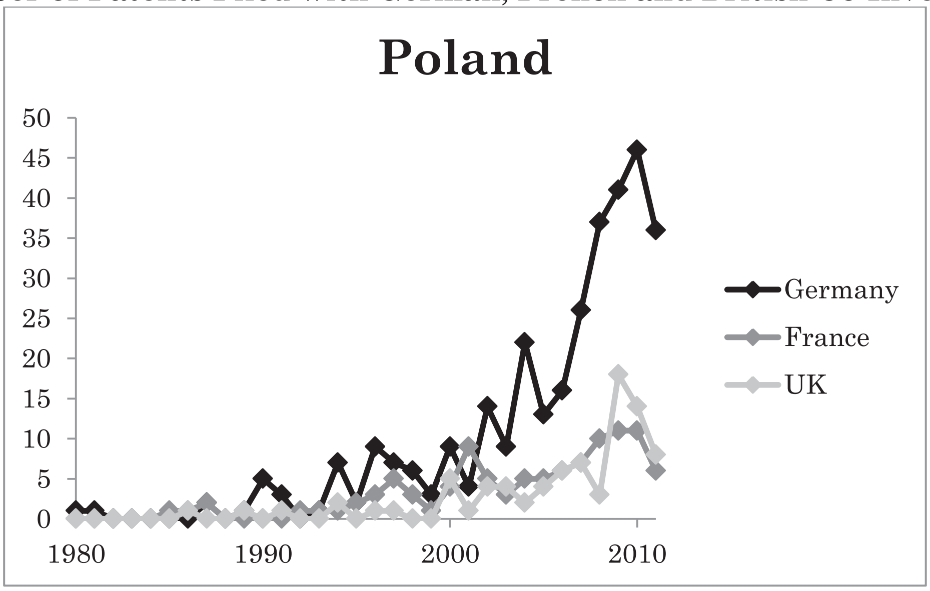
4.2. General Framework

Patent collaborations measure technology diffusion. They are defined as the number of patents filed at the EPO by an inventor located in a European emerging country with a co-inventor from a European developed country. Using the example of Russia, it is possible that the patent applicant does not come from an EU member country. The variable PAT_{ijt} denotes the number of patents filed by an inventor from the emerging country i with a co-inventor from the developed country j at time t i.e. the number of patent collaborations. The main problem is that statistics may integrate simple inventor movements.

Let us study a significant example of patent collaboration. We focus on the European Union. Figure 4.2 illustrates the evolution of Polish patent collaborations with three European developed countries over 1980-2011.

-Figure 4.2-

Poland's Patent Collaborations (Priority Date) over 1980-2011: Evolution of the Number of Patents Filed with German, French and British Co-Inventors



Source: OECD.

We analyze the evolution of the number of patents filed by Polish inventors with German, French and British co-inventors. Poland joined the European Union in 2004. The number of patent collaborations with German co-inventors sharply increased from 2005. Such an example proves that the European integration may have a significant impact on patent collaborations. Nevertheless, we cannot draw the same conclusion for collaborations with French and British co-inventors. Other variables may impact patent collaborations. For example, geographic distance seems to be a significant source because Poland and Germany share a common border.

We attempt to identify potential determinants of international technology diffusion. According to previous studies and economic intuitions, the following variables are potential determinants.

- The effect of the European integration is the main issue. We aim to determine whether or not technology diffusion to Eastern European countries is higher after integrating the European Union (EU). The European integration means that members have to remove all trade barriers on imports from other members. In this way, this is an (imperfect) measure of free trade. We denote by EU_{it} a dummy variable equal to one if the emerging country i is an EU member and zero, otherwise. The economic literature has illustrated a positive impact of such a dummy variable (**Picci, 2010**; **Cappelli and Montobbio, 2016**). In Chapter 3, we found a positive impact of policy instruments implemented by the South on technology diffusion. But the structure was completely different. Now, we focus on patent collaborations. Therefore, we expect a positive impact of the European integration.
- Technology collaborations may be greater when countries share a common border. We denote by CB_{ij} a dummy variable equal to one when countries i and j share a common border and to zero, otherwise. According to the economic literature, the expected impact is positive (**Guellec and Van Pottelsberghe de la Potterie, 2001**).
- Geographic distance may also influence technology diffusion via patent collaborations for the same reason. We denote by $DIST_{ij}$ the geographic distance between countries i and j. The economic literature illustrates such negative impacts (**Maggioni et al., 2007**; **Montobbio and Sterzi, 2013**). The expected impact is negative.
- Patent collaborations may depend on each country's market size. We can use two indicators: population and GDP. We denote by POP_{it} (POP_{jt}) country i (j)'s population and Y_{it} (Y_{jt}) country i (j)'s GDP. **Montobbio and Sterzi (2013)** study the impact of labor force and show that the effect can be either positive or negative. Even if our variables are different, their expected impact is also ambiguous. For example, innovations may increase with GDP and population. Inventors from developed countries may be encouraged to collaborate with foreign inventors. But they may also be encouraged to file patents in their own country rather than the emerging country owing to a stronger market size.
- Income inequalities between the two countries may reduce collaborations. We aim to verify whether or not the economic proximity is a significant determinant of technology diffusion by using the ratio of GDP per capita y_{it}/y_{jt} between emerging and developed countries, where $y_{it} = Y_{it}/POP_{it}$ and $y_{jt} = Y_{jt}/POP_{jt}$. We expect an increase in collaborations when income inequalities decrease (i.e. when the ratio increases).
- R&D expenditures may significantly impact technology diffusion because they measure innovations. Furthermore, the role of human capital may be prominent since R&D expenditures are knowledge investments. We denote by R_{it} (R_{jt}) emerging (developed) country i (j)'s R&D expenditures at time t. According to the economic literature, R&D investment is a channel for technology diffusion (**Eaton and Kortum, 1996**; **Xu, 2000**; **Griffith, Redding and Van Reneen, 2004**; **Keller, 2004**). The expected impact is therefore positive.
- The effect of technological gap may be a significant determinant. It relates to the difference in the level of innovations between the two countries. We analyze the impact of the ratio of R&D expenditures as percentage of GDP denoted by r_{it}/r_{jt},

where $r_{it} = R_{it}/Y_{it}$ and $r_{jt} = R_{jt}/Y_{jt}$. The technological gap decreases when the ratio increases. The reason is that emerging countries' R&D expenditures are lower than developed countries'.[23]

- We analyze the impact of technological distance defined as the difference in the structure of innovations. It relates to technological proximity mentioned in the economic literature. We denote by TD_{ijt} the technological distance between the country i and the country j at time t. We use a method close to **Jaffe (1988)**. We use the number of patents filed by domestic inventors for the 36 technologies of the WIPO database. We calculate the share of the number of patents over the total number of patents for each technology. Then, we calculate the sum of the difference in shares between the two countries in absolute terms for the 36 technologies at each period. Denoting k the index for technologies and pat the share of patents, we have: $TD_{ijt} = \sum_{k=1}^{k=36} |pat_{itk} - pat_{jtk}|$. An increase in such a variable leads to an increase in technological distance i.e. a drop in technological proximity. **Montobbio and Sterzi (2013)** prove that technological proximity is positive. Therefore, the expected sign of the impact of technological distance is negative.
- We also study the impact of public expenditures on education. It represents another way to measure investments in human capital with respect to R&D investments.
- Finally, technology diffusion may depend on bilateral trade and FDI (**Grossman and Helpman, 1991**; **Coe and Helpman, 1995**; **Eaton and Kortum, 2002**; **Keller, 2004**). Trade and FDI foster business relationships. Therefore, the effect on technological collaborations may be positive. We denote by X_{ijt} emerging country i's exports to developed country j, M_{ijt} emerging country i's imports from developed country j, and FDI_{ijt} emerging country i's FDI from developed country j. The expected impacts of these variables are positive.

Table 4.1 summarizes the expected impact of each explanatory variable on technology diffusion via patent collaborations.

-Table 4.1-

Expected Impact of Each Explanatory Variable

EU_{it} +	CB_{ij} +	$DIST_{ij}$ –	Y_{it} +/–	Y_{jt} +/–	POP_{it} +/–	POP_{jt} +/–	y_{it}/y_{jt} +	R_{it} +
R_{jt} +	r_{it}/r_{jt} +	TD_{ijt} –	EDU_{it} +	EDU_{jt} +	X_{ijt} +	M_{ijt} +	FDI_{ijt} +	

Source: author.

4.3. Data

We use panel data with:

- 13 emerging countries (index i):
  - 8 EU members since 2004: Czech Republic, Estonia, Lithuania, Latvia, Hungary, Poland, Slovakia, Slovenia
  - 2 EU members since 2007: Romania, Bulgaria

[23] The ratio r_{it}/r_{jt} is lower than one for 1042 cases over 1092 in our database.

    - 3 non EU members: Russia, Ukraine, Croatia[24]
- 7 European developed countries (index j): France, Germany, United Kingdom, Austria, Belgium, Netherlands, Italy
- Over the period 2000-2011 (index t)

Table 4.2 illustrates the definition and the source of data. Data are collected from several sources: OECD, CEPII, World Bank WDI, WIPO and COMTRADE. Descriptive statistics are in Appendix 4A.

PAT_{ijt} denotes the number of patent collaborations between i and j. Data are collected from the OECD database as the number of patent applications at the priority date filed by an inventor located in the country i with a foreign co-inventor located in the country j. The priority date is the filing date of the very first application for a specific invention. Therefore, it is interesting to collect the number of applications at this date since there is a lag between the real beginning of collaborations and the filing date. From PAT_{ijt}, we can define a dummy variable equal to one if $PAT_{ijt} \geq 1$ and zero, otherwise. $P(PAT_{ijt} \geq 1)$ denotes the probability of patent collaborations.

-Table 4.2-

Definition and Source for Each Variable

Variable	Definition	Source
PAT_{ijt}	Number of patent applications (at the priority date) filed at the EPO by an inventor from the emerging country i with a co-inventor from the developed country j at time t.	OECD
EU_{it}	Dummy variable equal to one if the emerging country i is a European Union member at time t and zero, otherwise.	-
CB_{ij}	Dummy variable equal to one if the emerging country i shares a common border with the developed country j and to zero, otherwise.	-
$DIST_{ij}$	Geographic distance between the emerging country i's biggest city and the developed country j's, in kilometers.	CEPII
Y_{it}	Gross Domestic Product of the emerging country i at time t, in USD.	World Bank WDI
Y_{jt}	Gross Domestic Product of the developed country j at time t, in USD.	World Bank WDI
POP_{it}	Population in the emerging country i at time t, number of residents.	World Bank WDI
POP_{jt}	Population in the developed country j at time t, number of residents.	World Bank WDI
R_{it}	R&D expenditures of the emerging country i at time t, in USD.	World Bank WDI
R_{jt}	R&D expenditures of the developed country j at time t, in USD.	World Bank WDI
PAT_{itk}[25]	Number of patents filed by an inventor located in the country i at time t for the technology k.	WIPO
PAT_{jtk}	Number of patents filed by an inventor located in the country j at time t for the technology k.	WIPO
EDU_{it}	Public expenditures on education of the emerging country i at time t, in USD.	World Bank WDI
EDU_{jt}	Public expenditures on education of the developed country j at time t, in USD.	World Bank WDI
X_{ijt}	Exports of goods from the emerging country i to the developed country j at time t, in USD.	COMTRADE
M_{ijt}	Imports of goods of the emerging country i from the developed country j at time t, in USD.	COMTRADE
FDI_{ijt}	Foreign Direct Investments stock from the developed country j to the emerging country i at time t, in USD.	OECD

Source: author.

[24] Croatia is an EU member since 2013.

[25] The share of patents for the technology k is given by: $pat_{itk} = PAT_{itk} / (\sum_{k=1}^{k=36} PAT_{itk})$.

Table 4.3 illustrates the number of cases in which the emerging country is an EU member and those in which patent collaboration occurs, over 1,092 cases. Emerging countries are EU members in about 53 percent of the 1,092 cases. Too high a share would lead to biased results. Furthermore, patent collaboration occurs in 23 percent of the cases when emerging countries are EU members. It only occurs in 20 percent of the cases when they are not. Nevertheless, when emerging countries are EU members, patent collaboration does not occur in 29 percent of the cases.

-Table 4.3-

Data Description for the European Union Integration and the Probability of Patent Collaborations

	Number of Country Pairs			Frequency		
$PAT_{ijt} \geq 1$ $EU_{it} = 1$	Yes	No	Total	Yes	No	Total
Yes	252	322	574	0.2308	0.2949	0.5256
No	220	298	518	0.2014	0.2729	0.4744
Total	472	620	1,092	0.4322	0.5678	1

Source: author.

4.4. Probability of Patent Collaborations under Logit Estimations

We run Logit estimations in which the explained variable is the probability of patent collaborations $P(PAT_{ijt} \geq 1)$. In the regression (A), we estimate the direct impact of emerging countries' European integration. We integrate gravity equations variables in the regression (B) by using GDP as the measure of market sizes. We use populations instead of GDP in the regression (C). We also estimate the impact of income inequalities in the regression (D) by using the ratio of GDP per capita. We study the impact of R&D expenditures in the regression (E), the ratio of the share of R&D expenditures in GDP and the technological distance in the regression (F), and public expenditures on education in the regression (G). Finally, we study the impact of exports, imports and FDI in the regression (H). Table 4.4 illustrates the marginal effects for each regression.

We run Hausman tests for each regression to choose between country fixed effects (dummy for each country i and each country j) and country pair random effects. We also run Fischer tests to estimate whether or not time fixed effects are significant. Finally, we test for multi-collinearity by using the method of Variance Inflation Factors (VIF) (see Appendix 4.B). The correlation matrix confirms the results, at the end of Appendix 4.A.

Populations and GDP must be integrated separately. The VIF test indicates a multi-collinearity problem. Correlation coefficients equal 0.8190 for Western European countries and 0.9571 for Eastern European countries. GDP is also highly correlated with R&D expenditures, public expenditures on education, bilateral trade and FDI. Finally, we cannot integrate populations under the regression (G) owing to collinearity with public expenditures on education. According to the correlation matrix, correlation coefficients are high between R&D and population, and between exports and imports. Nevertheless, the results of the VIF tests allow us to study the impact of these variables in the same regression.

Furthermore, the value of marginal effects may change with the value of explanatory variables. We calculate marginal effects for $EU_{it} = 1$ and for $EU_{it} = 0$. We find that the value of marginal effects is the same under both cases compared to "at-means" marginal effects.

-Table 4.4-

Marginal Effects under Logit Estimations

$P(PAT_{ijt} \geq 1)$	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EU_{it}	0.3058*	0.0352	0.0371	0.0061	0.0067	0.0401	0.0473	-0.0025
	(0.1695)	(0.0773)	(0.0596)	(0.0590)	(0.0780)	(0.0637)	(0.0792)	(0.0795)
CB_{ij}		0.1194	0.1198	0.1181	0.1235	0.1169	0.1202	0.1424
		(0.1305)	(0.1305)	(0.1292)	(0.1323)	(0.1288)	(0.1301)	(0.1380)
$\log DIST_{ij}$		-0.4499***	-0.4405***	-0.4422***	-0.4487***	-0.4336***	-0.4485***	-0.1784*
		(0.1198)	(0.1190)	(0.1187)	(0.1197)	(0.1164)	(0.1201)	(0.0995)
$\log Y_{it}$		0.3323*						
		(0.1830)						
$\log Y_{jt}$		0.2477						
		(0.5021)						
$\log POP_{it}$			0.4789		0.8401	0.4345		0.9363
			(0.9877)		(1.0900)	(0.9909)		(1.1101)
$\log POP_{jt}$			2.5116*		3.2268	2.4665*		2.9352
			(1.4574)		(2.4537)	(1.4601)		(2.4825)
$\log(y_{it}/y_{jt})$				0.2114**				
				(0.0879)				
$\log R_{it}$					0.1431			0.1403
					(0.1113)			(0.1185)
$\log R_{jt}$					0.1758			0.0614
					(0.3354)			(0.3248)
$\log(r_{it}/r_{jt})$						-0.0675		
						(0.1309)		
$\log TD_{ijt}$						0.1421		
						(0.1268)		
$\log EDU_{it}$							0.2095*	
							(0.1240)	
$\log EDU_{jt}$							-0.1393	
							(0.3791)	
$\log X_{ijt}$								0.1031**
								(0.0440)
$\log M_{ijt}$								0.0379
								(0.0737)
$\log FDI_{ijt}$								0.0348
								(0.0252)
Observations	1,092	1,092	1,092	1,092	1,092	1,092	1,092	1,092
Pseudo R-Squared	0.0002	0.3888	0.3770	0.3786	0.3888	0.3781	0.3886	0.3976
Panel Effects (a)	Country i RE	Country i FE Country j FE Time FE	Country i FE Country j FE	Country i FE Country j FE	Country i FE Country j FE Time FE	Country i FE Country j FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE
Hausman Test (b)	0.5367	0.0000	0.0374	0.0000	0.0000	0.0814	0.0000	0.0000
Fischer Test (c)	0.2790	0.0000	0.2754	0.1280	0.0000	0.2724	0.0000	0.0000

Source: author.
Note: Robust standard-errors are between parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. (a) FE (RE) denotes fixed (random) effects. (b) The choice between fixed and random effects depends on the Hausman test. Probabilities of random effects are given. (c) Time fixed effects depend on the Fischer test. Probabilities of non-significant time fixed effects are given.

According to the regression (A), the European integration significantly increases the probability of patent collaborations between emerging and developed countries without taking into account any other explanatory variable. Nevertheless, the results do not hold under other regressions. The marginal effects of the EU integration on the probability are no longer significant. The probability of patent collaborations depends on other variables.

There is a significant and negative impact of geographic distance. In spite of modern telecommunications, it seems complex to collaborate when co-inventors are geographically distant. Nevertheless, the existence of a common border does not significantly influence the probability of patent collaboration.

The levels of GDP and population measure the market size. According to the regression (B), the probability of patent collaborations significantly increases with emerging countries' GDP. The effect of developed countries' GDP is not significant. Developed countries' population significantly increases the probability under two cases while emerging countries' population has no significant impact. According to the regression (D), income inequalities significantly reduce the probability of patent collaborations because the effect of the ratio of GDP per capita is significant and positive.

R&D investments do not significantly increase the probability of patent collaborations. Technological gap is not a significant determinant because the effect of the ratio r_i/r_j is not significant. The impact of technological distance is not significant either. But the impact of emerging countries' public expenditures on education is positive and significant. The role of human capital is significant through education.

Emerging countries' exports to developed countries significantly increase the probability of patent collaborations while the effects of imports and FDI are not significant. Trade flows from emerging to developed countries significantly impact on technology diffusion.

4.5. Intensity of Patent Collaborations

We now study the impact of each explanatory variable on the intensity/number of patent collaborations. First, we run conditional estimations by considering the number of collaborations only when $PAT_{ijt} \geq 1$. Then, we run total estimations.

4.5.1. Conditional Estimations

Here, the explained variable is the number of patent collaborations in the cases in which they occur. As a consequence, the number of observations now equals 620. Table 4.5 illustrates the results.

-Table 4.5-

Results of Poisson Conditional Estimations

$\log PAT_{ijt}/PAT_{ijt} \geq 1$	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EU_{it}	0.2006**	0.1907	0.2889***	0.2357***	0.2024**	0.2881***	0.1781	0.2037**
	(0.0950)	(0.1217)	(0.0935)	(0.0686)	(0.0993)	(0.0939)	(0.1157)	(0.1017)
CB_{ij}		0.1083	0.5088**	0.1074	0.1064	0.5412**	0.1089	0.0179
		(0.0930)	(0.2596)	(0.0928)	(0.0932)	(0.2604)	(0.0929)	(0.1026)
$\log DIST_{ij}$		-0.3638***	-0.2917*	-0.3543***	-0.3690***	-0.2917	-0.3613***	-0.2068
		(0.1342)	(0.1767)	(0.1328)	(0.1349)	(-0.1785)	(0.1345)	(0.1584)
$\log Y_{it}$		0.0181						
		(0.2015)						
$\log Y_{jt}$		0.8625						
		(0.6719)						
$\log POP_{it}$			0.3396***		1.8603	0.3431***		1.7347
			(0.0604)		(1.9608)	(0.0628)		(1.8851)
$\log POP_{jt}$			0.5220***		0.5873	0.5293***		-0.4990
			(0.0906)		(1.8884)	(0.0920)		(1.8423)
$\log(y_{it}/y_{jt})$				0.0713				
				(0.0749)				
$\log R_{it}$					0.2319			0.2272
					(0.1653)			(0.1778)
$\log R_{jt}$					0.7622			0.7358
					(0.5201)			(0.5098)
$\log(r_{it}/r_{jt})$						0.0873		
						(0.1281)		
$\log TD_{ijt}$						0.0912		
						(0.2442)		
$\log EDU_{it}$							-0.0184	
							(0.1305)	
$\log EDU_{jt}$							0.0451	
							(0.4897)	
$\log X_{ijt}$								0.2195***
								(0.0553)
$\log M_{ijt}$								-0.0546
								(0.1257)
$\log FDI_{ijt}$								0.0457
								(0.0449)
Constant	-0.1152	-21.2493	-12.912***	1.6262	-59.4399	-12.989***	0.8901	-44.7150
	(0.1309)	(18.3818)	(1.7130)	(0.7749)	(46.8354)	(1.7337)	(14.4675)	(45.5816)
Observations	620	620	620	620	620	620	620	620
Pseudo R-Squared	0.0015	0.1780	0.1093	0.1748	0.1788	0.1108	0.1776	0.1826
Panel Effects	Country i RE	Country i FE Country j FE Time FE	Pair ij RE	Country i FE Country j FE	Country i FE Country j FE Time FE	Pair ij RE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE
Hausman Test	0.6622	0.0001	0.2618	0.0000	0.0000	0.1555	0.0000	0.0004
Fischer Test	0.8417	0.0005	0.9319	0.9092	0.0000	0.8992	0.0001	0.0010

Source: author.
Note: Robust standard-errors are between parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

The number of patent collaborations generally significantly increases with the EU integration. Now, integrating other explanatory variables, the impact remains significantly positive except for the regression (B).

The impact of common border is now significantly positive under two cases while its impact on the probability is not significant. The impact of geographic distance is significantly negative under five cases. But it is no longer significant in regressions (F) and (H). Distance is no longer a significant determinant of the intensity of patent collaborations with bilateral trade and FDI.

The impact of each GDP is not significant. But the effect of each country's population is significantly positive in regressions (B) and (F). The market size is a significant determinant of patent collaborations through populations.

The human capital does not seem to be a significant determinant because the impacts of R&D expenditures, technological gap and public expenditures on education are not significant. The effect of technological distance is not significant either.

Finally, there is again a significant and positive impact of emerging countries' exports while the impacts of imports and FDI are not significant.

We also run conditional OLS/GLS estimations (see Appendix 4.C). The main changes are the following. First, with OLS/GLS estimations, the impact of common borders is always significantly positive while the effect is only significant under two cases with Poisson estimations. Second, we find one case in which developed countries' population significantly reduces the intensity of collaborations. Third, emerging countries' R&D expenditures significantly increase collaborations under one case while the effect is never significant under Poisson estimations. The results generally hold, otherwise.

4.5.2. Total Estimations

We run Poisson total estimations by using the entire database. We integrate the cases in which the number of patent collaborations equals zero. The explained variable is PAT_{ijt}. Table 4.6 illustrates the results.

The number of patent collaborations always increases with the European integration for each regression. There is a strong and positive impact of exports as in previous tables. Geographic distance still significantly reduces collaborations. The levels of population are also significant and positive determinants. We do not find any case in which developed countries' population significantly reduces the number of patent collaborations. The impacts of GDP and income inequalities are still not significant. Technological gap and technological distance are now negative and significant determinants. The impact of the ratio r_{it}/r_{jt} is positive and significant. Another difference with respect to conditional estimations is that common border is no longer a significant determinant of the number of patent collaborations.

-Table 4.6-

Results under Poisson Total Estimations

PAT_{ijt}	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EU_{it}	0.3099***	0.2384*	0.3329***	0.2202*	0.3162***	0.2887***	0.2098*	0.3220***
	(0.0791)	(0.1256)	(0.0780)	(0.1225)	(0.1086)	(0.0804)	(0.1204)	(0.1138)
CB_{ij}		0.0024	0.4826	0.0018	0.0001	0.5011	0.0016	-0.1648
		(0.1093)	(0.4344)	(0.1090)	(0.1093)	(0.4365)	(0.1085)	(0.1139)
$\log DIST_{ij}$		-0.7765***	-1.1360***	-0.7770***	-0.7768***	-1.0490***	-0.7775***	-0.4597***
		(0.1204)	(0.2687)	(0.1203)	(0.1204)	(0.2680)	(0.1200)	(0.1489)
$\log Y_{it}$		-0.2416						
		(0.2385)						
$\log Y_{jt}$		0.5221						
		(0.7763)						
$\log POP_{it}$			0.7107***		3.2370	0.6843***		3.0309
			(0.0774)		(2.0912)	(0.0796)		(1.9616)
$\log POP_{jt}$			1.0563***		-0.8068	1.0496***		-2.6456
			(0.1152)		(2.3455)	(0.1158)		(2.2423)
$\log(y_{it}/y_{jt})$				-0.2940				
				(0.2137)				
$\log R_{it}$					0.1922			0.1376
					(0.1874)			(0.1885)
$\log R_{jt}$					0.3894			0.3669
					(0.5692)			(0.5522)
$\log(r_{it}/r_{jt})$						0.3182**		
						(0.1356)		
$\log TD_{ijt}$						-0.3046*		
						(0.1570)		
$\log EDU_{it}$							-0.2316	
							(0.1586)	
$\log EDU_{jt}$							0.0320	
							(0.5705)	
$\log X_{ijt}$								0.4005***
								(0.0657)
$\log M_{ijt}$								-0.0059
								(0.1276)
$\log FDI_{ijt}$								0.0550
								(0.0476)
Constant	0.7673***	-2.7972	-21.5217	4.3796***	-47.2896	-21.3344***	9.9823	-24.1735
	(0.2643)	(21.7444)	(2.3872)	(0.7779)	(55.0151)	(2.4040)	(16.8031)	(51.8154)
Observations	1,092	1,092	1,092	1,092	1,092	1,092	1,092	1,092
Pseudo R-Squared	0.0158	0.5996	0.4392	0.5997	0.6001	0.4414	0.5997	0.6094
Panel Effects	Country i RE Time FE	Country i FE Country j FE Time FE	Pair ij RE Time FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE	Pair ij RE Time FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE
Hausman Test	0.5113	0.0000	0.7452	0.0000	0.0000	0.7807	0.0000	0.0000
Fischer Test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Source: author.
Note: Robust standard-errors are between parentheses. $^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

4.6. Summary and Discussion

Let us summarize and discuss the results.

- The European integration is a significant determinant of technology diffusion via patent collaborations. It especially increases the number of patent collaborations. The effect on the probability of patent collaborations is not significant by considering other explanatory variables. The European integration increases technological collaborations as compared to the case in which emerging countries are not European members. Such a result means that the technology diffusion (via patent collaborations) is greater under free trade and free human movements. **Picci (2010)** generally finds a positive impact of the European integration on internationalized patents. But he also finds a negative and significant impact under one case. **Cappelli and Montobbio (2016)** also find a positive impact of the European integration. The results in the empirical economic literature concerning the impact of policy instruments on technology diffusion are ambiguous. Some papers show a positive impact of free trade. For example, **Bustos (2011)** explains that the MERCOSUR integration has involved technology upgrading in Argentina because firms have been encouraged to use new technologies. But other studies mention a positive impact of policy instruments (**Jaffe and Stavins, 1995**; **Van Dijk and Szirmai, 2006**).

- Geographic distance is also a significant determinant by significantly reducing both the number and the probability of patent collaborations. In spite of modern telecommunications, it seems complex to collaborate when co-inventors are geographically distant. Nevertheless, the impact of exports is more significant than that of geographic distance. The economic literature also finds a significant negative impact. Using an OLS estimation, **Maggioni and al. (2007)** also study the European case and find an elasticity of -1 while our significant elasticities vary over [0.25,0.3] (see Appendix 4.C).
- Sharing a common border significantly increases the number of patent collaborations under conditional estimations even if we integrate the levels of trade and FDI. Potential co-inventors can work together more easily when countries share common borders. The impact is greater than that of distance in this case. But the effect on the probability of patent collaborations is not significant. A common border involves a large number of collaborations in Europe but does not influence the probability of collaborations. However, the results do not hold under Poisson total estimations. **Guellec and Van Pottelsberghe de la Potterie (2001)** always find a positive and significant effect of the common border under TOBIT estimations. In our study, the positive effect is not systematically significant.
- Emerging countries' exports to developed countries are a strong determinant of both the number and the probability of patent collaborations while the effects of imports and FDI are not significant. These results relate to "learning-by-exporting" because exporters need to use modern technologies to be competitive. *"A domestic firm might through its exporting activity come into contact with foreign technology* [**Keller, 2010**, p. 817]*."* Previous studies demonstrate the existence of a "learning-by-exporting" effect (**Rhee, Ross-Larson and Pursell, 1984**; **Bernard and Jensen, 1999**). But other studies show that the effect is not significant (**Clerides, Lach and Tybout, 1998**).
- Our results illustrate that the role of imports and FDI is not significant while the economic literature shows that they are important channels for technology diffusion (**Coe and Helpman, 1995**; **Eaton and Kortum, 2002**; **Keller, 2004**; **Keller, 2010**). Nevertheless, **Montobbio and Sterzi (2013)** also find a non-significant impact of FDI on patent collaborations under Poisson estimations while the effect of trade is only significant for two cases over eight.
- Emerging countries' economic growth encourages inventors from developed countries to innovate with domestic partners but does not influence the number of collaborations. The impact of developed countries' GDP is never significant.

- The impact of the level of each population on the probability and the number of collaborations is positive. Nevertheless, we find one case in which developed countries' population significantly reduces the number of collaborations under OLS/GLS estimations. Inventors from developed countries may be encouraged to file patents in their domestic countries instead of emerging countries due to higher market sizes. Market sizes are significant determinants of technological collaborations, otherwise.
- Income inequalities significantly reduce the probability of patent collaborations because the impact of the ratio of GDP per capita is significantly positive under the Logit estimation. European Union has to reduce income inequalities between members to increase technology diffusion. But it does not significantly influence the number of collaborations.
- Emerging countries' R&D expenditures only significantly influence the number of patent collaborations under OLS/GLS conditional estimations. The impact of developed countries' R&D is not significant. There is a negative and significant impact of technological gap on the intensity of collaborations under Poisson total estimations. The European Union should promote Eastern European countries' R&D expenditures in order to reduce technological inequalities. Finally, emerging countries' public expenditures on education significantly increase the probability of patent collaborations. Therefore, human capital is a significant determinant. But the effect on the intensity is not significant. The economic literature also illustrates a positive impact of the human capital (**Eaton and Korturm, 1996**; **Xu, 2000**).
- The impact of technological distance is only significant under the Poisson total estimation. It significantly reduces the intensity of the patent collaborations. The impact is not significant under other estimations. **Montobbio and Sterzi (2013)** also find cases in which the impact of the technological proximity is not significant.

In this chapter, emerging countries' exports to developed countries is the most significant determinant of patent collaborations. Therefore, the most significant channel for technology diffusion seems to be the level of trade from emerging countries to rich countries.

4.7. Robustness Test: the European Union Integration Length

Previously, we have studied the impact of the Eastern countries' European integration on the probability and the intensity of patent collaborations with Western European countries. The results show that the European integration has a significant and positive impact on the intensity of patent collaborations while the impact on the probability is not significant.

Let us study now the impact of the number of years from the EU integration to 2011. We call such a number of years as "the European Union integration length." We denote by EUL_{it} the country i's European integration length. Since the first instance of Eastern countries' European integration was in 2004, we have: $EUL_{it} \in [0,8]$. We aim to verify whether or not the results hold by using such a quantitative variable instead of a dummy variable.

Appendix 4.D illustrates the results of Logit, OLS/GLS and Poisson estimations. The results generally hold with the European integration length. The effect on the probability is not significant but the impact on the intensity is still positive and significant. Nevertheless, coefficients are lower than those in previous sections. They are between 0.03 and 0.12 while they were always greater than 0.2 in previous sections. The signs of the impact of the European integration length and the impact of the dummy variable are the same. But the impact of the dummy variable is stronger.

As regard the impact of other explanatory variables, the common border significantly reduces the number of patent collaborations under the regression (H) with Poisson total estimations. Emerging countries' public expenditures on education significantly increases the intensity of collaborations by using OLS/GLS estimations. The ratio of R&D no longer significantly influences the intensity with Poisson total estimations. Technological distance significantly increases the intensity of patent collaborations under OLS/GLD estimations. The results generally hold, otherwise.

4.8. Concluding Remarks

In this chapter, we study the impact of potential determinants of technology diffusion via patent collaborations by running econometric estimations with panel data for Eastern and Western European countries (91 country pairs, over 2000-2011). First, we study the impact on the probability of patent collaborations under Logit estimations. Then, we study the impact on the intensity of collaborations under OLS/GLS and Poisson conditional estimations, and Poisson total estimations. We analyze the impact of the European integration on collaborations. We also integrate other explanatory variables like geographic distance, common borders, GDP, populations, income inequalities, exports, imports, FDI, R&D expenditures, technological gap, technological distance and public expenditures on education.

The results show that the European integration is not a significant determinant of the probability of patent collaborations for emerging countries. But it significantly increases the intensity of patent collaborations. Therefore, there is an interest in joining the European Union in order to benefit from stronger technology diffusion from other European countries. Such an example means that both emerging and rich countries should liberalize their economies to enhance technology diffusion. Using the number of years from the European integration to 2011 instead of the dummy variable, the results generally hold.

There is also a crucial effect of exports from emerging to developed countries that relates to "learning-by-exporting" because exports lead to business relationships. Exporters may innovate and collaborate with foreign inventors owing to such relationships. Geographic distance and populations are other significant determinants.

Appendix to Chapter 4

4.A. Descriptive Statistics

-Table 4.7-

Descriptive Statistics

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
PAT_{ijt}	1,092	2.9798	5.8670	0	48
EU_{it}	1,092	0.4743	0.4996	0	1
CB_{ij}	1,092	0.0879	0.2833	0	1
$DIST_{ij}$	1,092	1313.118	536.8261	59.6172	2510.88
Y_{it}	1,092	1.53e+10	2.90e+11	5.69e+09	1.90e+12
Y_{jt}	1,092	1.51e+12	1.04e+12	1.96e+11	3.75e+12
POP_{it}	1,092	2.28e+07	3.76e+07	1.33e+06	1.47e+08
POP_{jt}	1,092	4.28e+07	2.80e+07	8.01e+06	8.25e+07
R_{it}	1,092	1.49e+09	3.20e+09	3.37e+07	2.08e+10
R_{jt}	1,092	3.06e+10	2.57e+10	3.80e+09	1.09e+11
r_{it}/r_{jt}	1,092	0.0869	0.2125	0.0007	1.7827
TD_{ijt}	1,092	0.7281	0.1804	0.2872	1.4915
EDU_{it}	1,092	6.83e+09	1.26e+10	3.04e+08	8.85e+10
EDU_{jt}	1,092	7.48e+10	5.07e+10	1.10e+10	1.81e+11
X_{ijt}	1,092	3.26e+09	6.85e+09	1.14e+07	6.12e+10
M_{ijt}	1,092	2.76e+09	5.22e+09	1.88e+07	4.85e+10
FDI_{ijt}	1,092	3.10e+09	5.68e+09	618,947.1	3.91e+10

Source: author.

4.B. Multi-Collinearity Tests: Variance Inflation Factors (VIF) and Partial Correlation Matrix

-Table 4.8-

VIF with $P(PAT_{ijt} \geq 1)$

	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EU_{it}	1.09	1.13	1.41	1.65	1.14	1.12	1.93
CB_{ij}	1.81	1.85	1.73	1.86	1.85	1.80	1.95
$\log DIST_{ij}$	2.07	2.19	1.96	2.33	2.44	2.10	3.37
$\log Y_{it}$	1.03						
$\log Y_{jt}$	1.25						
$\log POP_{it}$		1.21		3.54	1.52		4.57
$\log POP_{jt}$		1.19		6.50	1.26		8.06
$\log(y_{it}/y_{jt})$			1.65				
$\log R_{it}$				3.16			4.18
$\log R_{jt}$				6.89			7.67
$\log(r_{it}/r_{jt})$					1.05		
$\log TD_{ijt}$					1.45		
$\log EDU_{it}$						1.04	
$\log EDU_{jt}$						1.30	
$\log X_{ijt}$							8.44
$\log M_{ijt}$							9.26
$\log FDI_{ijt}$							3.39

Source: author.
Note: We consider that there is a multi-collinearity problem when at least one VIF is greater than ten. These tests are implemented after OLS estimations.

-Table 4.9-

VIF with $\log PAT_{ijt}/(PAT_{ijt} \geq 1)$

	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EU_{it}	1.19	1.14	1.39	1.55	1.15	1.24	1.76
CB_{ij}	1.97	2.03	1.86	2.08	2.08	1.95	2.27
$\log DIST_{ij}$	2.74	3.16	2.17	3.29	3.37	2.77	4.20
$\log Y_{it}$	1.13						
$\log Y_{jt}$	1.40						
$\log POP_{it}$		1.54		4.01	1.79		4.58
$\log POP_{jt}$		1.45		6.63	1.55		8.51
$\log(y_{it}/y_{jt})$			1.65				
$\log R_{it}$				3.03			4.22
$\log R_{jt}$				6.55			7.66
$\log(r_{it}/r_{jt})$					1.05		
$\log TD_{ijt}$					1.32		
$\log EDU_{it}$						1.12	
$\log EDU_{jt}$						1.46	
$\log X_{ijt}$							6.21
$\log M_{ijt}$							7.70
$\log FDI_{ijt}$							3.75

Source: author.
Note: We consider that there is a multi-collinearity problem when at least one VIF is greater than ten. These tests are implemented after OLS estimations.

-Table 4.10-

VIF with PAT_{ijt}

	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EU_{it}	1.09	1.13	1.41	1.65	1.13	1.12	1.93
CB_{ij}	1.81	1.85	1.73	1.86	1.85	1.80	1.95
$\log DIST_{ij}$	2.07	2.19	1.96	2.33	2.44	2.10	3.37
$\log Y_{it}$	1.03						
$\log Y_{jt}$	1.25						
$\log POP_{it}$		1.21		3.54	1.49		4.57
$\log POP_{jt}$		1.19		6.50	1.26		8.06
$\log(y_{it}/y_{jt})$			1.65				
$\log R_{it}$				3.16			4.18
$\log R_{jt}$				6.89			7.67
$\log(r_{it}/r_{jt})$					1.07		
$\log TD_{ijt}$					1.45		
$\log EDU_{it}$						1.04	
$\log EDU_{jt}$						1.30	
$\log X_{ijt}$							8.44
$\log M_{ijt}$							9.26
$\log FDI_{ijt}$							3.39

Source: author.

Note: We consider that there is a multi-collinearity problem when at least one VIF is greater than ten. These tests are implemented after OLS estimations.

-Table 4.11-

Partial Correlation Matrix

	EU_{it}	CB_{ij}	$\log DIST_{ij}$	$\log Y_{it}$	$\log Y_{jt}$	$\log POP_{it}$	$\log POP_{jt}$
EU_{it}	1						
CB_{ij}	0.1196	1					
$\log DIST_{ij}$	-0.1460	-0.6484	1				
$\log Y_{it}$	0.0653	0.0664	0.0433	1			
$\log Y_{jt}$	0.1889	-0.0739	0.3259	0.1154	1		
$\log POP_{it}$	-0.3198	-0.0606	0.2442	0.8190	-0.0031	1	
$\log POP_{jt}$	0.0106	-0.0731	0.3312	0.0066	0.9571	-0.0002	1
$\log R_{it}$	0.0911	0.1026	-0.0046	0.9515	0.1162	0.7201	0.0069
$\log R_{jt}$	0.2065	-0.0204	0.2775	0.1275	0.9592	-0.0035	0.8957
$\log EDU_{it}$	0.0882	0.0687	0.0503	0.9869	0.1227	0.7925	0.0071
$\log EDU_{jt}$	0.2232	-0.0979	0.3460	0.1372	0.9909	-0.0037	0.9313
$\log X_{ijt}$	0.1846	0.3202	-0.1785	0.7562	0.4007	0.5444	0.3366
$\log M_{ijt}$	0.2109	0.3388	-0.2115	0.7301	0.4524	0.4900	0.3749
$\log FDI_{ijt}$	0.1148	0.2807	-0.3118	0.7080	0.0801	0.4877	-0.0024
	$\log R_{it}$	$\log R_{jt}$	$\log EDU_{it}$	$\log EDU_{jt}$	$\log X_{ijt}$	$\log M_{ijt}$	$\log FDI_{ijt}$
$\log R_{it}$	1						
$\log R_{jt}$	0.1295	1					
$\log EDU_{it}$	0.9548	0.1361	1				
$\log EDU_{jt}$	0.1390	0.9590	0.1466	1			
$\log X_{ijt}$	0.7302	0.4068	0.7350	0.3871	1		
$\log M_{ijt}$	0.7037	0.4755	0.7187	0.4327	0.9203	1	
$\log FDI_{ijt}$	0.6933	0.1389	0.6773	0.0805	0.7467	0.7442	1

Source: author.

4.C. OLS/GLS Conditional Estimations

-Table 4.12-

Results of OLS/GLS Conditional Estimations

$\log PAT_{ijt}/PAT_{ijt} \geq 1$	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EU_{it}	0.2141***	0.2130**	0.2907***	0.2546***	0.2168**	0.2892***	0.2022*	0.2048**
	(0.0746)	(0.1077)	(0.0766)	(0.0776)	(0.1004)	(0.0771)	(0.1050)	(0.1022)
CB_{ij}		0.4347***	0.8316***	0.4327***	0.4338***	0.8352***	0.4347***	0.3158***
		(0.1157)	(0.2926)	(0.1140)	(0.1137)	(0.2977)	(0.1149)	(0.1178)
$\log DIST_{ij}$		-0.2723**	-0.1354	-0.2584**	-0.2749**	-0.1397	-0.2705**	-0.0827
		(0.1131)	(0.1514)	(0.1093)	(0.1139)	(0.1608)	(0.1130)	(0.1307)
$\log Y_{it}$		0.0319						
		(0.2299)						
$\log Y_{jt}$		0.6042						
		(0.6526)						
$\log POP_{it}$			0.3193***		3.2267*	0.3218***		2.8255*
			(0.0555)		(1.7952)	(0.0588)		(1.7174)
$\log POP_{jt}$			0.4557***		-3.8484	0.4570***		-4.3647*
			(0.0853)		(2.6232)	(0.0900)		(2.5327)
$\log(y_{it}/y_{jt})$				0.0599				
				(0.1027)				
$\log R_{it}$					0.3092*			0.2794
					(0.1678)			(0.1797)
$\log R_{jt}$					0.4079			0.4132
					(0.4412)			(0.4322)
$\log(r_{it}/r_{jt})$						0.0124		
						(0.0932)		
$\log TD_{ijt}$						0.0343		
						(0.1689)		
$\log EDU_{it}$							-0.0150	
							(0.1466)	
$\log EDU_{jt}$							0.3604	
							(0.5334)	
$\log X_{ijt}$								0.2252***
								(0.0493)
$\log M_{ijt}$								0.0305
								(0.1106)
$\log FDI_{ijt}$								0.0032
								(0.0357)
Constant	0.8728***	-14.3821	- 11.4498***	2.0675***	-4.2005	-11.4599	-7.4255	4.5526
	(0.1199)	(18.1564)	(1.6147)	(0.6732)	(53.4929)	(1.6665)	(15.3694)	(51.3941)
Observations	620	620	620	620	620	620	620	620
R-Squared	0.0048	0.5977	0.3499	0.5891	0.6142	0.3505	0.6324	0.6163
Panel Effects	Country *i* RE	Country *i* FE Country *j* FE Time FE	Pair *ij* RE	Country *i* FE Country *j* FE	Country *i* FE Country *j* FE Time FE	Pair *ij* RE	Country *i* FE Country *j* FE Time FE	Country *i* FE Country *j* FE Time FE
Hausman Test	0.6884	0.0000	0.2618	0.0000	0.0000	0.1555	0.0000	0.0000
Fischer Test	0.7547	0.0000	0.5949	0.6462	0.0000	0.5359	0.0000	0.0000

Source: author.
Note: Robust standard-errors are between parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

4.D. European Integration Length

-Table 4.13-

Results of Logit Estimations with the European Integration Length

$P(PAT_{ijt} \geq 1)$	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EUL_{it}	0.0344	0.0071	-0.0129	-0.0091	-0.0124	-0.0115	0.0130	-0.0165
	(0.0315)	(0.0162)	(0.0124)	(0.0107)	(0.0168)	(0.0200)	(0.0177)	(0.0177)
CB_{ij}		0.1307	0.1180	0.1183	0.1224	0.1185	0.1198	0.1441
		(0.5679)	(0.1302)	(0.1289)	(0.1321)	(0.1311)	(0.1303)	(0.1380)
$\log DIST_{ij}$		-0.4500***	-0.4411***	-0.4420***	-0.4488***	-0.4400***	-0.4487***	-0.1770*
		(0.1196)	(0.1198)	(0.1189)	(0.1201)	(0.1179)	(0.1198)	(0.0990)
$\log Y_{it}$		0.3531*						
		(0.1923)						
$\log Y_{jt}$		0.2516						
		(0.5005)						
$\log POP_{it}$			0.2986		1.0858	0.6074		1.2508
			(0.9685)		(1.1340)	(1.0773)		(1.1575)
$\log POP_{jt}$			4.0545		3.1048	2.6651		2.7717
			(1.6493)		(2.4547)	(2.4068)		(2.4896)
$\log(y_{it}/y_{jt})$				0.3039***				
				(0.0977)				
$\log R_{it}$					0.1738			0.1826
					(0.1166)			(0.1261)
$\log R_{jt}$					0.1535			0.0398
					(0.3375)			(0.3261)
$\log(r_{it}/r_{jt})$						0.0495		
						(0.1583)		
$\log TD_{ijt}$						0.1310		
						(0.1333)		
$\log EDU_{it}$							0.2451*	
							(0.1392)	
$\log EDU_{jt}$							-0.1402	
							(0.3791)	
$\log X_{ijt}$								0.1114**
								(0.0450)
$\log M_{ijt}$								0.0275
								(0.0743)
$\log FDI_{ijt}$								0.0332
								(0.0250)
Observations	1,092	1,092	1,092	1,092	1,092	1,092	1,092	1,092
Pseudo R-Squared	0.0001	0.3888	0.3774	0.3796	0.3892	0.3883	0.3886	0.3981
Panel Effects	Country i RE	Country i FE Country j FE Time FE	Country i FE Country j FE	Country i FE Country j FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE
Hausman Test	0.6983	0.0000	0.0037	0.0000	0.0000	0.0050	0.0000	0.0003
Fischer Test	0.2661	0.0000	0.1088	0.4965	0.0000	0.0900	0.0000	0.0002

Source: author.
Note: Robust standard-errors are between parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

-Table 4.14-

Results of OLS/GLS Conditional Estimations with the European Union Integration Length

$\log PAT_{ijt}/PAT_{ijt} \geq 1$	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EUL_{it}	0.0437***	0.0878***	0.0618***	0.0467***	0.0557***	0.0623***	0.0953***	0.0544***
	(0.8859)	(0.0253)	(0.0148)	(0.0134)	(0.0199)	(0.0161)	(0.0277)	(0.0208)
CB_{ij}		0.4312***	0.4363***	0.4357***	0.4317***	0.4510***	0.4305***	0.3042***
		(0.1143)	(0.1123)	(0.1129)	(0.1132)	(0.1118)	(0.1139)	(0.1174)
$\log DIST_{ij}$		-0.2678**	-0.2552**	-0.2580**	-0.2692**	-0.2351**	-0.2673**	-0.0725
		(0.1134)	(0.1106)	(0.1105)	(0.1143)	(0.1105)	(0.1135)	(0.1317)
$\log Y_{it}$		0.4563						
		(0.2865)						
$\log Y_{jt}$		0.5783						
		(0.6473)						
$\log POP_{it}$			-0.1104		1.7259	0.0308		1.4248
			(1.7038)		(1.8985)	(1.7062)		(1.7939)
$\log POP_{jt}$			-2.1462		-3.6668	-2.2204		-4.1429*
			(1.9915)		(2.5959)	(2.0188)		(2.5091)
$\log(y_{it}/y_{jt})$				0.0758				
				(0.1073)				
$\log R_{it}$					0.2948*			0.2435
					(0.1688)			(0.1805)
$\log R_{jt}$					0.4382			0.4346
					(0.4403)			(0.4317)
$\log(r_{it}/r_{jt})$						-0.0295		
						(0.2156)		
$\log TD_{ijt}$						0.2574*		
						(0.1558)		
$\log EDU_{it}$							0.3437*	
							(0.2035)	
$\log EDU_{jt}$							0.3299	
							(0.5294)	
$\log X_{ijt}$								0.2130***
								(0.0509)
$\log M_{ijt}$								0.0644
								(0.1135)
$\log FDI_{ijt}$								0.0045
								(0.0359)
Constant	0.8859***	-24.3033	37.928	2.0938***	16.7570	36.8692	-16.0277	23.3863
	(0.1333)	(18.3652)	(48.6419)	(0.6696)	(53.7223)	(48.7420)	(15.5777)	(51.1759)
Observations	620	620	620	620	620	620	620	620
R-Squared	0.0105	0.6287	0.5905	0.6317	0.6283	0.6314	0.6288	0.6191
Panel Effects	Country i RE	Country i FE Country j FE Time FE	Country i FE Country j FE	Country i FE Country j FE	Country i FE Country j FE Time FE	Country i FE Country j FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE
Hausman Test	0.8376	0.0041	0.0000	0.0000	0.0185	0.0002	0.0006	0.0000
Fischer Test	0.8455	0.0000	0.1661	0.5469	0.0000	0.1513	0.0000	0.0000

Source: author.

Note: Robust standard-errors are between parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

-Table 4.15-

Results of Poisson Conditional Estimations with the European Union Integration Length

$\log PAT_{ijt}/PAT_{ijt} \geq 1$	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EUL_{it}	0.0373**	0.0774***	0.0503***	0.0398***	0.0511***	0.0506***	0.0833***	0.0526***
	(0.0159)	(0.0280)	(0.0157)	(0.0102)	(0.0181)	(0.0159)	(0.0299)	(0.0193)
CB_{ij}		0.1085	0.5167**	0.1134	0.1071	0.5459**	0.1086	0.0082
		(0.0926)	(0.2567)	(0.0924)	(0.0929)	(0.2572)	(0.0928)	(0.1019)
$\log DIST_{ij}$		-0.3584***	-0.2882*	-0.3531***	-0.3628***	-0.3003*	-0.3577***	-0.1925
		(0.1348)	(0.1751)	(0.1339)	(0.1356)	(0.1771)	(0.1354)	(0.1612)
$\log Y_{it}$		0.4072						
		(0.2784)						
$\log Y_{jt}$		0.8209						
		(0.6659)						
$\log POP_{it}$			0.3305***		0.4380	0.3394***		0.3557
			(0.0594)		(2.1080)	(0.0621)		(1.9898)
$\log POP_{jt}$			0.5193***		0.7071	0.5305***		-2.2710
			(0.0900)		(1.8750)	(0.0914)		(1.8467)
$\log(y_{it}/y_{jt})$				0.0675				
				(0.0747)				
$\log R_{it}$					0.2479			0.2139
					(0.1674)			(0.1778)
$\log R_{jt}$					0.7610			0.7320
					(0.5178)			(0.5063)
$\log(r_{it}/r_{jt})$						0.0435		
						(0.1275)		
$\log TD_{ijt}$						0.1469		
						(0.2428)		
$\log EDU_{it}$							0.3051	
							(0.2028)	
$\log EDU_{jt}$							0.0072	
							(0.4871)	
$\log X_{ijt}$								0.2076***
								(0.0568)
$\log M_{ijt}$								-0.0112
								(0.1302)
$\log FDI_{ijt}$								0.0464
								(0.0445)
Constant	-0.0965	-29.8856	-12.7050***	1.6515**	-38.6948	-12.9350	-6.5609	-26.4481
	(0.1256)	(18.6060)	(1.6898)	(0.7773)	(47.1551)	(1.8088)	(14.8502)	(45.3152)
Observations	620	620	620	620	620	620	620	620
Pseudo R-Squared	0.0105	0.1791	0.1104	0.1748	0.1793	0.1118	0.1787	0.1830
Panel Effects	Country i RE	Country i FE Country j FE Time FE	Pair ij RE	Country i FE Country j FE	Country i FE Country j FE Time FE	Pair ij RE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE
Hausman Test	0.8654	0.0000	0.8459	0.0000	0.0000	0.9131	0.0000	0.0000
Fischer Test	0.9021	0.0001	0.7614	0.7757	0.0000	0.7421	0.0000	0.0006

Source: author.

Note: Robust standard-errors are between parentheses. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

-Table 4.16-

Results of Poisson Total Estimations with the European Union Integration Length

PAT_{ijt}	(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)
EUL_{it}	0.0875***	0.1176***	0.0897***	0.1077***	0.0924***	0.0835***	0.1195***	0.0990***
	(0.0143)	(0.0293)	(0.0142)	(0.0279)	(0.0203)	(0.0235)	(0.0314)	(0.0215)
CB_{ij}		0.0020	0.4942	0.0014	-0.0011	0.4835	0.0018	-0.1827*
		(0.1063)	(0.4314)	(0.1061)	(0.1063)	(0.4344)	(0.1063)	(0.1102)
$\log DIST_{ij}$		-0.7761***	-1.1012***	-0.7782***	-0.7765***	-1.0593***	-0.7775***	-0.4325***
		(0.1213)	(0.2654)	(0.1209)	(0.1207)	(0.2657)	(0.1214)	(0.1525)
$\log Y_{it}$		0.3899						
		(0.3090)						
$\log Y_{jt}$		0.4816						
		(0.7645)						
$\log POP_{it}$			0.7110***		0.8571	0.6905***		0.7361
			(0.0768)		(2.2309)	(0.0781)		(2.0691)
$\log POP_{jt}$			1.0514***		-0.7727	1.0425***		-2.1656
			(0.1141)		(2.2420)	(0.1146)		(2.1629)
$\log(y_{it}/y_{jt})$				0.2535				
				(0.2762)				
$\log R_{it}$					0.2575			0.1421
					(0.1880)			(0.1880)
$\log R_{jt}$					0.3561			0.3322
					(0.5666)			(0.5460)
$\log(r_{it}/r_{jt})$						0.1318		
						(0.1424)		
$\log TD_{ijt}$						-0.2512**		
						(0.1568)		
$\log EDU_{it}$							0.2639	
							(0.2299)	
$\log EDU_{jt}$							-0.0261	
							(0.5544)	
$\log X_{ijt}$								0.3670***
								(0.0679)
$\log M_{ijt}$								0.0983
								(0.1336)
$\log FDI_{ijt}$								0.0612
								(0.0470)
Constant	0.7673***	-17.4938	-21.6894***	5.0752***	-9.9857	-21.4841***	-1.4240	4.1869
	(0.2638)	(21.8895)	(2.3587)	(0.7789)	(55.8570)	(2.3708)	(16.9357)	(51.6949)
Observations	1,092	1,092	1,092	1,092	1,092	1,092	1,092	1,092
Pseudo R-Squared	0.0082	0.6022	0.4456	0.6019	0.6023	0.4488	0.6020	0.6115
Panel Effects	Country i RE Time FE	Country i FE Country j FE Time FE	Pair ij RE Time FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE	Pair ij RE Time FE	Country i FE Country j FE Time FE	Country i FE Country j FE Time FE
Hausman Test	0.6578	0.0000	0.7282	0.0074	0.0000	0.2197	0.0000	0.0000
Fischer Test	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Source: author.
Note: Robust standard-errors are between parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

-CHAPTER 5-

General Conclusion

In those chapters, we have tried to answer the questions raised at the end of the general introduction (Chapter 0). This study does not aim to prove that free trade is better than protectionism in terms of innovations and technology diffusion. We cannot provide a general conclusion: (i) several forms of protectionist barriers exist and involve different economic impacts; (ii) such impacts may depend on parameters and functional forms. Nevertheless, our results prove that the implementation of several policy instruments (for example, production subsidies) has a positive economic impact. Therefore, governments may *"play a major role in certain international industries* [**Spencer and Brander, 1983**, p. 717]*."*

Chapter 1 and 2 illustrate that industrialized countries that face growing competition from emerging countries should implement policy instruments in order to increase their competitiveness. Innovations measured by R&D expenditures may increase with these policy instruments. The implementation of import tariffs, production subsidies, R&D subsidies and minimum prices by Northern governments may increase domestic firms' R&D investments. These instruments involve a profit-shifting from Southern firms to Northern firms due to governmental supports. Northern firms increase their R&D investments in order to increase profit gains. The results hold with both process and product R&D.

The results show the special features of quantitative restrictions. The implementation of import quotas has an ambiguous impact on R&D investments. We have defined two types of quota: a relatively binding quota and a strongly binding quota. The implementation of the former reduces domestic R&D investments. With a strongly binding quota, we have determined a threshold such as R&D investments equal free trade levels. Therefore, R&D investments increase with a more binding quota as compared to free trade, and vice versa with a less binding quota. Such a policy instrument may reduce R&D investments. We can explain this result by the nature of the quota. Quotas change strategic relationships between competitors (**Bhagwati, 1968**; **Krishna, 1989**). Southern countries may implement VER in order to reduce Northern countries' R&D expenditures.

Chapter 3 studies the issue of technology diffusion. Southern countries may benefit from competitive advantages owing to lower production costs. But they may face competitive disadvantages in terms of technological endowments. Technology diffusion allows Southern firms to use modern technologies previously discovered in Northern countries. First, we have designed a theoretical model in which a new technology is patented in order to slow down technology diffusion. We have analyzed the impact of the implementation of policy instruments on the patent length that measures the speed of the new technology diffusion. Northern countries' policy instruments slow down the new technology diffusion by increasing the patent length except for an import quota.

Finally, Chapter 4 makes an empirical analysis on technology diffusion via an econometric estimation. Patent collaborations measure technology diffusion. We have focused on collaborations between Eastern Europe and Western European countries over 2000-2011. We have studied the impact of the European Union integration of Eastern countries. The European integration is not a significant determinant of the probability of patent collaborations. However, the impact is significant and positive for the intensity (number) of patent collaborations. We have also analyzed the impact of other potential determinants of patent collaborations like bilateral trade, FDI, geographical and technological distances, human capital, market sizes and common borders.

Last, let us mention a few directions in which we might possibly extend the previous studies. All these extensions are interesting and could be studied in future research.

- First, it would be interesting to study retaliations since the implementation of a tariff in the Northern country may imply retaliatory tariff in the Southern country with the potential WTO permission, and the implementation of a production subsidy may lead to countervailing duty in the foreign country. We have studied the impact of Southern countries' policy instruments at the end of Chapter 3 as a first extension. Nevertheless, it can be dramatically improved. It would be interesting to make a welfare analysis by considering that each government implements policy instruments at the same time.
- We could also design a different theoretical framework. We have focused on a North-South duopoly. We could model an oligopoly with N firms, design North-North and South-South frameworks, or add a third country. Furthermore, we could design endogenous growth models.
- A third possible extension may consist in the introduction of asymmetrical information in Chapters 1 and 2. The Northern government may not know the probability of R&D success or the level of marginal cost if the R&D succeeds. Another option is that the R&D is similar to an effort undertaken by the firm and the government may not be in a position to control this level of effort.
- About Chapter 3, the main extension would be the introduction of a licensing contract between the North and the South (see the second possible extension). In this case, the speed of the new technology diffusion would depend on the date of the licensing contract. This section could be improved. Another possible extension would be the introduction of trade secrets rather than patents.
- About the econometric estimation in Chapter 4, another explained variable could measure technology diffusion. For example, FDI in R&D from the North to the South are a potential measure. We might also study the impact of policy instruments like taxes and subsidies.

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Other References (Data, Definitions, Newspaper Articles)

Business Dictionary. Definitions.

CEPII. Database.

COMTRADE. United Nations International Trade Statistics.

DESTATIS. Indicators.

Europa. European Commission Official Website.

European Patent Office. Espacenet Patent Search.

France Diplomatie. "Tailored funding with the Public Investment Bank" (December 5, 2013), Official Website of the French Ministry of Foreign Affairs.

INSEE. Definitions and Methods.

MAcMap. International Trade Centre.

OECD. OECD.Stat Database.

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WIPO. Intellectual Property Statistics Data Center.

World Bank. World Development Indicators.

World Health Organization. Global Health Observatory Data.

WTO. Agreement on Subsidies and Countervailing Measures.

WTO. Non-Tariff Measures.

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Policy Instruments, Research and Development, Innovations and Technology Diffusion in a North-South Structure

Abstract: We study the relationship between policy instruments, innovations through Research and Development (R&D) and technology diffusion in a North-South structure. First, we analyze the impact of the implementation of policy instruments by a Northern country on domestic (process and product) R&D expenditures in a theoretical framework. The North faces competition from a low-cost Southern country. The results show that policy instruments increase R&D expenditures except for an import quota. Then, we focus on the issue of technology diffusion from the North to the South. We design a dynamic theoretical model in which the North files a patent to increase the monopoly period with a new technology. Previous policy instruments slow down technology diffusion except for an import quota again. Nevertheless, retaliations implemented by the South may accelerate it. Finally, we make an empirical study through econometric estimations of potential determinants of the technology diffusion from the North to the South measured by patent collaborations. We show that the European Union integration of Eastern European countries significantly increases the intensity of patent collaborations with Western European countries while the effect on the probability of collaboration is not significant.

JEL Classifications: F12; F13; O30; O33
Keywords: Policy Instruments; Research and Development; Technology Diffusion; Patent Collaborations

Instruments Politiques, Recherche et Développement, Innovations et Diffusion de la Technologie dans une Structure Nord-Sud

Résumé : Nous étudions la relation entre la mise en place d'instruments politiques, des innovations via la Recherche et Développement (R&D) et la diffusion de la technologie dans une structure Nord-Sud. Nous analysons d'abord l'impact de la mise en place d'instruments politiques d'un pays du Nord sur l'investissement en R&D domestique (de procédé puis de produit) dans un cadre théorique. Le Nord fait face à la concurrence venant d'un pays du sud à faibles coûts de production. Les résultats montrent que ces instruments stimulent les dépenses en R&D mis à part avec un quota sur importations. Nous nous concentrons ensuite sur la question de la diffusion de la technologie du Nord vers le Sud. Nous utilisons un modèle dynamique théorique dans lequel le Nord publie un brevet pour augmenter la durée de monopole concernant l'utilisation d'une nouvelle technologie. Les instruments politiques précédents ralentissent la diffusion technologique mis à part le quota, une nouvelle fois. Néanmoins, des représailles mises en place par le Sud peuvent l'accélérer. Enfin, nous réalisons une étude empirique à l'aide d'estimations économétriques au niveau des déterminants potentiels de la diffusion de la technologie entre le Nord et le Sud, mesurée par les collaborations de brevet. Nous montrons que l'intégration à l'Union Européenne des pays d'Europe de l'Est augmente significativement l'intensité des collaborations avec les pays d'Europe de l'Ouest alors que l'effet sur la probabilité de collaboration n'est pas significatif.

Mots-clés : Instruments Politiques ; Recherche et Développement ; Diffusion de la Technologie ; Collaborations de Brevet

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